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ABSTRACT

In discussing the relationship between cognitive development (perception, pattern recognition, and memory) and reading processes, this paper especially emphasizes developmental factors. After an overview of some issues that bear on how written language is processed, the paper presents a discussion of pattern recognition, including general pattern recognition models, perception of letter strings, and word recognition. This is followed by a discussion of memory, including functions of information storage, a rationale for discreteness of storage mechanisms, and levels of information storage. A section on sensory information storage discusses iconic memory, development and iconic memory, information scanning in iconic memory, and data- and resource-limited processing. A section on precategorical storage includes methodological problems; echoic memory; precategorical acoustic storage; and development, precategorical storage, and reading. The section on short-term memory discusses the general nature of short-term memory, language processing, and development and short-term memory. (TJ)

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# COGNITIVE DEVELOPMENT AND READING PROCESSES

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# COGNITIVE DEVELOPMENT AND READING PROCESSES

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## I. Introduction

The last decade has witnessed a rapid growth in research on the nature and development of basic cognitive processes. Much of the impetus for this activity has come from researchers inspired by modern information-processing approaches to basic psychological issues. As the theoretical explanantions and methodologies generated by this research continue to mature, the possibility for fruitful extention to related areas increases. The study of reading processes constitutes one area where such attempts are beginning. In the present paper the relationship between cognitive processes (e.g., perception, pattern recognition, memory) and reading processes (e.g., how written language is processed and comes to be comprehended) is explored. Particular emphasis is placed on developmental factors. To the extent that this and future attempts are successful, our understanding of both cognitive and reading processes will be enriched. The significance to psychology of a better understanding of reading processes was long ago noted and is reflected in the following statement by a pioneering psychologist and reading researcher, Edmund B. Huey: " to completely analyze what we do when we read would almost be the acme of a psychologist's achievements, for it would be to describe very many of the most intricate workings of the human mind" (Huey, 1908, p.6). If Huey's statement is accurate we should stand well advised as to, not only the relationship between reading research and psychology, but also reading's complex and difficult nature.

Discussion of the relationship between cognitive and reading processes would be made easier if we could begin with a general statement about the nature of reading processes. Unfortunately, reading processes are not well understood,

and there is presently no general consensus on many basic issues. The processes involved appear to be quite complex, varying with different competency levels, written materials, purposes for reading, etc. The present paper presents a general overview of some issues which bear on how written language is processed and how the course of this processing changes with development. A general information-processing view of perception and pattern recognition is first briefly discussed. Letter string recognition, word recognition, and memorial processes are then explored in detail. Hopefully these discussions can serve as a general introduction which will assist in the identification and clarification of some major issues which bridge cognitive development and reading processes.

## II. Perception: An Overview

### A. General Rationale

To behave effectively in the world one must continually make decisions about and interpretations of the environment. These interpretations are based on information that one extracts from the environment and relates to internally existing structures or knowledge. The decision that a ball is round is based on information received by the visual system. Likewise, the visual system extracts the information embedded in the shape of a letter which allows us to decide that the shape is or is not a member of a particular category of shapes. Word and sentence perception is more complicated. To read, for example, one must use the visual information on a page to reconstruct a fairly specific linguistic message. This reconstruction must presumably result in comprehension that is quite similar to that comprehension which would have occured had the message been received as oral language. We normally assume that a written message which the beginning reader has difficulty comprehending would be relatively easily understood if it were read to him by another individual. Presumably this individual must learn to transform written information into a form which is as

comprehensible to him as speech. One of the major tasks of reading research is to identify how such transformations are made and why they appear to be so difficult for many individuals. A major step towards answering these questions will have been made when we understand more about how oral and visual language processing differ.

## B. Information Gathering

The nervous system gathers extensive information about external objects and events through its various sensory organs. The eye, serving as the primary source of external information in reading, extracts information from the optical array (e.g., a written page) during a series of brief eye fixations of a few hundred milliseconds duration. Only the area of the visual field which is projected onto the foveal region of the retina, constituting a few degrees of visual angle, is in clear focus during these fixations. Indeed, evidence is beginning to accumulate which suggests that under fairly normal reading conditions skilled readers are unable to make semantic interpretations of words falling as few as 7 to 12 character spaces beyond the point of fixation (Rayner, 1975). High-speed eye movements called "saccades" move the eyes about the visual field between fixations. These saccadic movements are "ballistic" in nature--that is, once their movement has begun, the eyes move to a computed endpoint without correction. Essentially no additional visual information is received while saccadic movement is underway.

Presumably contour changes make up the lines, curves, and angles that are detected by the viual system and provide the elementary information used to distinguish between shapes (e.g., letters). Such contour changes have been found to be the most probably fixation points for many different types of pictures; the assumption is often made that these points contain the most useful information, even in situations where there are no eye movements (Norton &

Stark, 1971). Whatever the specific form taken by information during its earliest detection by the sensory system, the energy contacting the sensory organs is transformed into neural impulses which must maintain essential aspects of the transmitted information across the variety of physical changes which occur as processing progresses.

C. Operations Performed on Information

Information must undergo numerous operations during processing which transform its nature in many ways. The need for a variety of operations becomes apparent when one considers factors such as the enormous quantity of potentially detectable information, the noisy contexts within which information is often embedded, the continual flux of proximal stimulation upon sensory organs, and the varying lengths of time required to process different materials. To process information efficiently, one must select for processing those environmental elements most relevant or useful for a given task. This selection is required because one's processing capacity is limited and only portions of the available information can be thoroughly analyzed. Information about letter size or "font" is often irrelevant and extensive processing capacity need not be expended on these features. Selective functioning must also take place at different processing levels. Peripherally, for example, one selects aspects of the visual field for foveal inspection; more centrally, relevant semantic elements are selected for attentive processing.

In addition to its selection, environmental information must be integrated into a coherent pattern, for much of a message's meaning can only be determined by taking note of the relationship between the constituent parts which make up the message. For example, reading involves the integration of a series of discrete informational chunks gathered during a series of brief eye fixations. In isolation these chunks are largely devoid of meaning. Newly acquired information must also constantly be assimilated or related to information already

existing within the organism, for information must be made sense of or interpreted in terms of pre-existing knowledge. Written material can be comprehended only after it has been identified as relating in a particular way to appropriate semantic representations. Even after its immediate use, information must often be processed in a manner which allows storage of its most relevant aspects for possible future use.

## III. Pattern Recognition

The words of a sentence are normally clearly perceived despite differing presentation rates and speaker dialects. Noisy backgrounds may at times obscure or mask particular portions of the constituent sounds of a sentence with little apparent effect on word perception. In an analogous fashion, there is little disruption of written word perception across a wide variety of graphic variations and distortions (Kolers, 1969, 1970, 1972). The patterns of physical energy impinging upon the retina fluxuate radically with each new eye fixation--yet the world is perceived as stable and whole, not as a series of brief visual snapshots. In other words, despite the varying and transitory nature of much proximal stimulation, the world is perceived as relatively unchanging and complete

One way to reconcile the seemingly paradoxical relationship between perception and proximal stimulation is to assume that perception involves more than a passive registration of environmental stimulation. Gibson (1969, 1971) has argued that one actually seeks out those aspects of the environmental stimulation which remain constant across various transformations. In contrast, Neisser (1967, 1968) has suggested that perceptions are constructs which one synthesized on the basis of interpretations of sensory data over time. Visual perception is held, in Neisser's view, to involve a memory which is schematic in nature, with successive eye fixations adding details to an individual's synthesied model of the external world and events. Because of the varied nature of the information on which constructed perception depends, the synthesizing mechanism presumably

must make the best and most useful interpretations possible, "filling in" details when necessary. Warren and Warren (1970) provide evidence for such constructive activity in speech perception under circumstances where a part of an acoustic message is absent without subjective detection. The ease with which one often"fills in" a missing, highly predictable item of text when reading a passage is another common example.

While a percept must be constructed or organized in a relatively rapid manner to be of value, the suggestion has often been made that instantaneous interpretation of sensory data may not always be desirable. Allowing perception to lag a little behind the actual intake of information can be useful, providing time necessary for use of context and redundancies (e.g., Miller, 1962; Warren & Warren, 1970).

## A. General Pattern Recognition Models

Although the nature of the processing machinery that analyzes sensory information and synthesizes a stable perception is largely unknown, we have already proposed certain operations which such machinery should be able to perform. Presumably this machinery should be able to select, organize, interpret, and store information. At some point in the processing sequence an analysis must be carried out which allows a pattern of sensory information (sounds, shapes,etc.) to be recognized as either equivalent to or different from other patterns of stimulation. Neisser (1967) has suggested that recognition (stimulus equivalence) can be considered to have occured when a stimulus evokes a single response. Speculations as to how the process of pattern recognition is carried out, although quite tentative, provide an interesting vehicle for exploring the whole question of recognition.

### 1. Template-matching Models

The early Gestalt psychologists argued that internal representations or "prototypes" (today often referred to as "templates") are matched against the

pattern of sensory information. The template which most closely matches the sensory data is selectively activated and recognition occurs. Problems with this early, simplistic version of a template-matching scheme for pattern recognition were soon apparent. Consider the letter "A" which is easily recognized despite many different fonts, hand writings, sizes, orientations, etc. Just what templates these differing versions of the letter "A" are matched against is unclear, unless there are separate templates for every potential variation of an object. One possible way to avoid such problems would be to conceive of the templates and being themselves constructed from smaller units, sets of features, or, simply the features themselves, such as lines, curves, angles, etc. Physiological research on cortical receptive fields in recent years has provided evidence for the existence of such feature detectors (e.g., Hubel, 1963). However, if the notion of a template is to be reduced to a unit the size of a feature, we should realize that the meaning of this word has become something quite different than what the early Gestalters had in mind.

2. The Pandemonium Model

An interesting feature-analytic scheme for pattern recognition was proposed by Selfridge and Neisser (1960). Referred to as "pandemonium," this scheme consists of a hierarchical arrangement of devices called "demons," which detect only particular patterns of encoded information. When a demon detects the particular pattern of information it seeks, it signals this finding to higher-level demons. The general process of lower-level demons signaling higher-level demons continues until signals reach high-level cognitive demons. When a cognitive demon detects the presence of the particular pattern of signals it "looks for" (e.g., the pattern of signals representing the distinctive features of the letter "A"), this cognitive demon begins emitting signals. The intensity of the signals emitted by a cognitive demon increases as a function of the

number of relevant signals received from below. Decision demons monitor this signalling and decide on the basis of the "pandemonium" below which pattern is most likely to be present. Pandemonium is potentially a powerful analytic scheme. If supplemented by ordering, orientation, and contextual demons, pandemonium could account for the identification of a wide variety of objects. Possibly this or a similar feature analysis takes place in early stages of pattern recognition. But it remains to be domonstrated just how such a scheme can accommodate the complexity of many recognition tasks, such as those involved in the comprehension of oral and written language.

Neisser (1967) proposed that information processing takes place in two general stages. The first or preattentive stage is characterized as global, wholistic, parallel, and crude; processing capacity at this level is large, and processing can occur without assistance from an attentional mechanism. In many respects the characteristics of the preattentive stage are compatible with those of the pandemonium model. The second or attentive stage contrasts with the first, for detailed, sequential, and deliberate processing occurs here. Processing capacity limitations are likely to be experienced at this level, for attention is required for processing material here; attention apparently aides in the interpretation of information and the synthesis of perception. A percept must be constructed in a manner which is as consistent as possible with the sensory information, the temporary context in which this information is embedded, and past experiences with similar information.

3. Analysis-by-synthesis Models

Various analysis-by-synthesis schemes have been proposed as possible ways to explain the constructive side of pattern recognition (e.g., Cooper, 1972; Halle & Stevens, 1962; Lindsay & Norman, 1972; Neisser, 1967, 1968; Norman, 1968, 1972; Stevens, 1972). Halle and Stevens (1962) proposed a scheme for speech recognition that is similar to Bruner's "hypothesis testing." They suggested

that the analysis of speech proceeds by attempting to recreate the sensory signal internally and then matching this synthesized version with the actual stored input. A hypothesized version is accepted when it closely matches the acoustic signal. While advocating a similar scheme for pattern recognition, Neisser (1967) pointed out that, in addition to a need for a mechanism which compares a hypothetical signal with the real one, an efficient procedure is needed for generating reasonable hypotheses. Early, automatic processing stages (e.g., a pandemonium) might function to limit the number of hypotheses generated. A useful strategy might involve a heavy use of context through a delay of analysis until large chunks of information were gathered. Researchers at the Haskins Laboratory have advocated an analysis-by-synthesis scheme for speech recognition whereby a tentatvie hypothesis is made about the nature of a speech signal (e.g., Cooper, 1972; Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Liberman, 1970). The tentative hypothesis is then used by some of the same mechanisms involved with speech production to guide in the synthesis of a hypothetical, internal sound form for the message. The sound form is then matched against the sensory signal and accepted if the match is close. Attempts have recently been made to extend such hypothesis testing schemes to reading (Cooper, 1972).

4. Characteristics of Pattern Recognition Systems

The above pattern recognition schemes must be considered quite speculative in nature, for little is known about how information processing actually proceeds. Alternative models are available. Gibson (1969), for example, rejects template-matching models and proposes instead that perception involves the identification of, or selective attending to, relevant or distinctive features. While many issues remain unresolved, it may be useful to speculate about some general characteristics which would appear to be useful for a variety of processing systems. A first general characteristic concerns the hierarchical arrangement of processing stages. Sensory information presumably activates

low-level processors which transform or recode information and then, in turn, activate higher-level processors. Such hierarchies, common in the nervous system (e.g., Hubel, 1963; Lindsay & Norman, 1972), allow a general "summing up" and reduction of information to take place. The summing up is needed because the initial variety and quantity of information receiving a preliminary analysis is large, and an adequate data-base must be available to insure the accurate processing of data that is often embedded in a noisy environment.

Another general characteristic concerns the active or constructive nature of pattern recognition. Some kinds of information apparently can not be accurately analyzed without aid from a special attentional mechanism which actively organizes and interprets the data. The processing at this level, or in this mode of activation, seems to be quite limited in its over-all capacity. This limitation places much of the processing burden on the more automated or preattentive levels, which must function as accurately as possible -- that is, processing at the preattentive levels must often involve accurate "best guesses". The attentional mechanism is likely to be a plastic device that has the ability to focus on information at various processing levels (e.g., LaBerge, 1972; LaBerge & Samuels, 1974). Processing which occurs below the level of attentional focus must be preattentive and automatic. The accuracy with which information is processed preattentively may vary a great deal. Thus, the information upon which attentional processing depends may be incomplete at times. When this is the case, some mechanism may have to fill in missing gaps or smooth out inconsistencies where possible.

A third general charactristic which would be useful for a pattern recognition system concerns the ability to analyze different types and levels of information simultaneously or in parallel. When one processes written material, the letter recognition, the order of letters, and the lengths and shapes of

words may all be in part processed simultaneously by different mechanisms. High-level processors may begin searching memory and constructing tentative interpretations with the very first signals from below, long before processing is completed at lower levels. Because much of the information contained in written passages is redundant, accurate high-level decisions are possible even when portions of the sensory input do not receive thorough analysis.

## B. Perception of Letter Strings

The above discussion presents a general overview of pattern recognition. The patterns most relevant for reading English are composed of letter strings, and so we will now take a brief look at research centering specifically on letter-string perception. Research on the perception of letter strings has a long history in psychology (e.g., Cattell, 1886; Huey, 1908), and while the advent of modern reaction time procedures and tachistoscopic devices has resulted in the abandonment of early tachistoscopic apparatus, many of the findings of those early psychologists still appear relevant today. Letter-string length and their "word-likeness" were important experimental manipulations ninety years ago, and they remain so.

### 1. Perception of Unstructured Letter Strings

One of the most basic observations in the study of letter-string perception is that perceptual performance for unstructured letter strings deteriorates as the number of letters in the array increases (e.g., Sperling, 1960; Reicher, 1969). While this finding may seem unremarkable, an interesting qualification has been noted in recent years. The number of letters in an array appears to be a vital variable only when the letters share features which make them difficult to distinguish (e.g., Egeth, Jonides, & Wall, 1972; Estes, 1972). Why this appears to be the case has yet to be determined, and while a thorough discussion of proposed explanations (cf. Smith & Spoehr, 1974) is beyond the scope of this paper, one possible explanation will be presented at a later point in this paper.

2. Perception of Structured Letter Strings

A second basic observation to come out of the study of letter-string perception is that subjects can report more letters from briefly presented word arrays than arrays which are composed of unstructured letter-strings. This effect is often referred to as the "word superiority effect" and was noted by Cattell (1886) using a whole report procedure. While a possible contaminatin factor with Cattell's whole report paradigm is differential memory for letters which form words as compared to letters forming unstructured strings, the word superiority effect has also been observed in a forced-choice, partial report paradigm (Reicher, 1969). This latter paradigm is likely to minimize the role played by memory; similar paradigms are reviewed in more detail below in the section discussing memory processes. Evidence of the word superiority effect is not restricted to adults, for this effect has been obtained for first- and third-grade children, although we should note that their performances were generally below those of adults (Gibson, Osser, & Pick, 1963).

C. Word Recognition: Feature Redundancy Models

1. The Problem

Findings such as the word superiority effect led many early psychologists to the view that word perception is not mediated by individual serial letter perception (e.g., Huey, 1908). This view runs counter to a common notion that one reads by sounding out words, letter by letter. Reading in this latter case would be mediated by sounds which are associated with the individual letters in a word. Linguists have often argued against so simple a reading phonics for English by demonstrating the irregularity of the correspondence between letters and the phonemes which they are assumed to symbolize (e.g., Wardaugh, 1969a, 1969b). Recent findings which are in part spin-offs from attempts at synthesizing speech support the view that there is often little one-to-one correspondence between units as small as an isolated phoneme (letter-sized) and recognizable

speech sounds (e.g., Cooper, 1972; Liberman, 1970; Liberman et al., 1967). Many phoneme-lengthed speech sounds are perceived differently in differing contexts. Additionally, many phonemes cannot be articulated without the accompanying articulation of other phonemes. Thus, both speech perception and production often appear to involve the transmission of contrasting information in parallel across phonlological segments somewhat larger than those of single phonemes (e.g., Liberman, 1970). In many ways phonemes, while possessing some degree of psychological reality (e.g., Fromkin, 1973), appear to be highly abstract units which are not always readily available for introspection (Foder & Bever, 1965; Savin & Bever, 1970; Savin, 1972). Some researchers have argued that the acquisition of competent reading skills is particularly difficult for many individuals in societies with alphabet-based orthographies directly as a result of the small size and abstract nature of the phonemes to which letters attempt to correspond (e.g., Elkonin, 1973; Gleitman & Rozin, 1973; Mattingley, 1972; Rozin, Poritsky, & Sotsky, 1971; Savin, 1972; Shankweiler & Liberman, 1972). Makita (1968) and Sakamoto & Makita (1973) presented evidence that the incidence of reading failure is many times lower in Japan than in countries which have an alphabetically based orthography. Written Japanese uses an orthographic system with individual symbols that correspond to syllabic- and morphemic-sized linguistic units.

Additional support for the view that learning to read an alphabetically based writing system is often particularly difficult was obtained in one study in which a group of American second-grade children with clear reading disabilities were taught to associate Chinese characters with English words (Rozin et al., 1971). These children found learning the appropriate paired-associations a fairly easy task, which once completed, allowed them to relatively easily learn to map strings of these Chinese characters onto the corresponding speech. Reading instruction programs have been developed in recent years which

explore the possibility of teaching orthography-to-sound correspondences for language units which are smaller than whole words, yet larger than single phonemes or letters (e. g., Gleitman & Rozin, 1973). Unfortunately, the effectiveness of such approaches has yet to be fully determined.

2. The Whole Word Feature-Analytic Model

Evidence that reading normally does not seem to involve sounding out each word letter-by-letter is not necessarily incompatible with the view that word recognition is mediated by prior individual letter identification. For letters may be serially matched against internal representations in memory prior to higher level processing (Gough, 1972). However, a number of models have been proposed which explore how reading might take place if word recognition is not mediated by individual letter perception. One of the most influential word recognition models is F. Smith's (1971) "feature-analytic" model which assumes that "words are identified directly from featural information without the intervening identification of any letters that make up the word" (Smith, 1971, p.128).

Smith argued that one learns to identify individual letters by developing a set of distinctive features which constitute significant differences between one letter configuration and another. When letters are strung together to form words one again develops sets of discriminating features. However, for the case of learning to categorize word configurations, the positions of features within the sequence are taken into account. A consequence of using the sequential information in word identification is that many of the features of the constituent letters are redundant and need not be processed. That is to say, fewer features of any given letter may need to be identified when that letter is presented in a word, as compared to when that letter is presented alone.

In Smith's view words contain far more information than is necessary to

be distinguishable and much of their redundant information need not be processed. Features are matched up with word categories without prior matching of features to letter categories. The word superiority effect can be explained by Smith's model, for it predicts that there are more features that must be identified to categorize a letter in an unrelated string than in a word. Additionally, nonwords are categorized letter-by-letter, while words are categorized as units.

Word configurations are recognized in Smith's feature-analytic model in a manner which is similar to the way in which many other object configurations are recognized -- a set of discriminating features in the configuration are matched against an appropriate feature list which is stored in memory. A competent English reader is able to read many thousands of words; presumably a tremendous number of discrete feature lists must be learned and stored by each individual. When we consider the wide variety of fonts which are encountered in normal reading, these feature lists must become either more complex in structure or more numerous. While learning to discriminate between a large number of shapes may seem like an arduous task, research on recognition memory suggests that both adults (e.g., Haber, 1970; Shepard, 1967) and children (Haith, 1971) are capable of recognizing tremendous numbers of pictures with relatively little effort. The extent to which these pictures are distinctive from one another may be an important variable here. The same thing may be true of our oral vocabularies, which are surprisingly large.

Chinese characters are presumably identified as separate symbols, and certainly it is hard to conceive of a phonics which specifies how one is to properly sound out words such as "of" or "women". But do we normally learn to identify English words as if they are wholes without prior identification of component segments? Learning a few Chinese characters may be a relatively easy task (e.g., Rozin et al., 1971), but the job of memorizing a large number of

characters proves to be a drawn-out and arduous task (e.g., Leong, 1973; Lotz, 1972); the opportunities for confusing even the relatively distinctive configurations of characters may increase greatly as a function of the number learned. Martin (1972) has indicated that Chinese scholars are able to read only a fraction of the characters in the Chinese dictionary. In contrast, English readers are able to read most of the words in their oral vocabulary without reference to a dictionary -- a tremendous number of words indeed. This latter fact would support the view that there are at least some differences in the ways in which Chinese and English orthographies can be processed. Additional support for distinguishing different orthographies is available in the finding that certain types of brain injuries apparently have a more deleterious effect on the reading of some types of orthographies than others (Geschwind, 1972; Luria, 1970).

3. Orthographic Structure Models

Although English orthography is seemingly replete with spelling irregularities, a strong case can be made for the view that a good deal of lawfulness underlies much of the apparent irregularity in English orthography (e.g., C. Chomsky, 1970; N. Chomsky, 1970; Halle, 1969: Reed, 1970; Venezkey, 1970; Venezkey & Calfee, 1970; Wardhaugh, 1969a). For example, C. Chomsky (1970) and N. Chomsky (1970) have suggested that English orthography may correspond closely, not so much directly to surface phonology, but to an underlying, abstract systemic lexicon. Words such as "nation" and "national" may be merely different surface forms of the same underlying lexical representation. N. Chomsky (1970) has even suggested that English may possess a "near-optimal" orthographic system. While this latter statement seems a bit extreme in light of the difficulties which many people have with English spelling and the complex and varied origins of English orthography (e.g., Francis, 1970), Chomsky does

succeed in demonstrating that English orthography appears more regular when linguistic levels beyond surface phonology are considered.

If extensive regularities exist between English orthography and either speech or some more abstract lexical representation, then in contrast to whole word recognition models, it is certainly possible that readers do at times make extensive use of their knowledge of spoken English in decoding written text. However imperfect written English is, it may in many ways be a visual model of the spoken language. The major job of a beginning reader may be to learn the invariant correspondence between the visual model and the spoken language.

Evidence which is relevant for distinguishing between the views that words are either recognized as sholes or as combinations of smaller patterns is found in research that explores the word superiority effect. This effect is found not to be limited to words, for a "superiority effect" is found for nonwords that conform to English phonological and orthographic rules in adults (e.g., Gibson, Pick, Osser, & Hammond, 1962; Baron & Thurstone, 1973) and in third-grade, but not in first-grade, children (Gibson, Osser, & Pick, 1963). Findings such as these create problems for Smith's feature-analytic model, with its emphasis on whole-word feature lists. How can we explain the superior perceptual performance found for nonwords for which there are presumably no such unique feature lists? One study presented deaf readers with nonwords which either did or did not approximate English spelling and found a superiority effect (Gibson, Shurcliff, & Yonas, 1960). The deaf readers presumably were influenced by English spelling patterns which conformed to English orthographic rules.

Possibly units larger than individual letters but smaller than whole words are recognized in a manner similar to that proposed by Smith. The results of Gibson et al. (1970) could be explained if word recognition is mediated by identification of units composed of spelling patterns which conformed to

English orthographic and phonological rules. Unfortunately, there are some unresolved problems with this latter word recognition view, for it is unclear how one could distinguish the end of one spelling segment from the beginning of another without prior categorization of individual letters (E. Smith & Spoehr, 1974).

4. Word Recognition in Connected Text

So far we have discussed the perception of written material only in so far as it relates to letter string and word perception. How closely the processes involved in word recognition parallel those involved in reading connected text is hotly debated. Some researchers have suggested that reading connected text normally involves recognition of units much larger than words and that instructional approaches for young children which emphasize word recognition are misguided (Goodman, 1969, 1972; F. Smith, 1972, 1973; F. Smith & Goodman, 1971).

In contrast to this view is one which argues that, while competent readers may often process written material in units larger than single words, the locus of the difficulties for beginning readers is found with the recognition of words and their components (Shankweiler & Liberman, 1972). Support for this latter view was obtained in a study that found a high correlation between the ability to read lists of words and connected text for second-grade children (Liberman, Shankweiler, Orlando, Harris, & Birt, 1971). While this correlation does not imply a causal relationship, it is certainly consistent with the view that word recognition is a prerequisite for reading skill development. But whatever the size of the orthographic unit initially decoded in reading, there can be little doubt that before one can comprehend connected text groups of words must at some point be procedded as structured entities.

Presentation of an adequate reading model is not possible at this time, for even the simpler word recognition models seem unable to completely account

for their more restricted set of data. Although our discussion of letter-string perception has left many questions unanswered, it has hopefully served as a useful vehicle for introducing some of the major points of view and basic phenomena which future models will have to consider.

## IV. Memory: An Overview

### A. Functions of Information Storage

There are two general reasons why the nervous system must preserve information over time. First, information must be stored while the activities of information gathering and processing take place, for the execution of these activities requires time. Second, the value of some aspects of analyzed information is not fully expended at the time of initial analysis, and these aspects must be stored for possible use at a future point in time. Information which is maintained while its ongoing analysis is in progress can be thought of as being preserved by a relatively temporary "processing-involved" storage mechanism. Likewise, information which has already undergone processing and which is retained for potential future use can be viewed as being reserved by a relatively permanent "future use" storage mechanism.

Both temporary and permanent storage are involved when one processes oral and written language. For example, a sentence can not be understood element-by-element or word-by-word, because the meaning of a sentence is not the projection of the individual element or word meanings. As a result, comprehension is possible only after the relationships between elements have been determined. Thus, the initial part of a sentence must be temporarily retained, allowing time for linguistic units of varying sizes to be accumulated and processed. In addition, information gathered at earlier points in time about the meaning of words, sentence structure, context, etc., must be brought into use if this sentence is to be properly interpreted. And after the sentence

has been comprehended, some aspects of the resulting interpretation may be stored for possible use at a future point in time.

B. Discreteness of Storage Mechanisms: A Rationale

Some difficulties exist with the assumption that memory is a system which can be "decoupled" in the laboratory from other cognitive processes, for memory may reflect the workings of the cognitive system as a whole, including various processes, strategies, controls, etc. (Reitman, 1972). Unfortunately, there are no direct ways to assess stored information independently from other aspects of cognitive functioning. Inferences about the structure of a storage system, the length of time it retains information, etc., are based on the influence information is assumed to have on particular responses. Different cognitive processes may be involved in memory tasks, which alter the characteristics of both memory and the information it contains. Therefore, functional criteria are important in decisions about the existence and nature of different types of information storage.

A distinction between mechanisms which retain information for different purposes and periods of time can be made on a functional basis and need not imply that structurally separate memories are necessarily involved. The characteristics which distinguish temporary from more permanent storage may reflect information in separate memories (e.g., Atkinson & Shiffrin, 1968; 1971; Waugh & Norman, 1965), information undergoing different modes of activation, e.g., with or without assistance from attention (e.g., Norman, 1968), or information which has undergone differing levels of processing (e.g., Craik & Lockhart, 1972). Although it is not clear how the memory system is structured, attempts which operationally distinguish various types or levels of storage are likely to be useful and can be made with some justification (Norman, 1968).

Much of the information contained in an incompletely analyzed message

has potential use that extends only over a brief duration, and as a result, much of this information need be retained only temporarily while the message is being processed. Indeed, retention of some aspects of information for a long duration might result in confusion with newly received information. In contrast, some of the aspects of a message which are available after interpretation has been effected have potential use that extends over an indefinite period of time, and therefore, must often be relatively permanently stored. For example, while the particular words and word-ordering of a message need be stored only while the message is being processed, the resulting meaning may be of value for a long period of time. Whatever the actual structure of the memory system, the mechanisms which are responsible for the varied characteristics of stored information, such as the relative permanence or availability of retained material, can be distinguished on functional bases.

C. Four Levels of Information Storage

Earlier in this paper we suggested that information processing proceeds in a hierarchical fashion. Presumably some of the lightly analyzed information at the bottom of this hierarchy is in need of further processing, and is therefore likely to be maintained by a temporary processing-involved storage mechanism. Once this information has been heavily analyzed and semantically interpreted at higher processing levels, the resulting information is more likely to be retained more permenently by a future-use storage mechanism. Our discussion of reading processes is largely concerned with how written material comes to be interpreted, and so the kinds of storage mechanisms which are involved in the processing that leads to these interpretations are of particular interest. For this reason, we will explore some relatively temporary storage mechanisms which appear to function in a manner that maintains information as it is undergoing various levels of active processing. Sensory information storage, precategorical storage, and short-term memory will each be discussed in turn, and each will be

related to reading processes and child development where possible. Our discussion of the storage mechanism which retains information for more lengthy durations, long-term memory, will be largely limited to the case where this memory is relevant to the discussion of the three less permenent types of storage mechanisms.

## V. Sensory Information Storage

### A. Iconic Memory

The lowest level of information storage which will be discussed in this paper concerns the retention of information by what has commonly been referred to as the sensory information store. This store seems to maintain a large and accurate record of sensory input while feature extraction and pattern recognition take place. A separate sensory information store may exist for each sensory modality, with the characteristics of each store reflecting various characteristics of their respective input modalities. The sensory information store for visual information is often referred to as the "iconic" memory (Neisser, 1967), and has been the most extensively studied sensory information store. The remaining discussion of storage at this level will be limited to a discussion of information acquired through the visual modality.

Although iconic storage presumably takes place in a low level information buffer, this storage does not appear to be solely a retinal phenomenon (Haber, 1970). Little selectivity seems to be indolved in the entering of visual information into iconic storage, for information appears to be automatically stored as soon as it is detected. Not much is known about the nature of the information stored iconically, but presumably the information is held in a relatively unanalyzed form. Possibly more than one type of information is maintained by iconic storage. For example, Hochberg (1970) suggests that both peripheral and fixated upon features play roles in guiding the location of eye fixations in reading. If Hochberg is correct, then iconic storage may involve

the retention of both detailed information registered by the fovea and low acuity data picked up more peripherally.

1. Partial Report Technique

Evidence of the existence of iconic memory initially came from the introspections of individuals attempting to recall large numbers of briefly presented visual stimuli. Although these individuals could normally only report between four and six stimulus items after each trial, they often reported that they had seen more items than they could recall. Sperling (1960, 1963) explored this phenomenon by contrasting a typical "whole report" procedure with a "partial report" procedure. Subjects under both procedures received fifty millisecond presentations of an array made up of three, four-letter rows. When a whole report report procedure was employed, subjects were simply asked to recall the letters after termination of the display. Subjects in this whole report condition were able to report each letter only about one-third of the time. Thus, they were able to recall about four letters on each trial.

The partial report procedure consisted of presenting either a high, medium, or low frequency tone following the termination of the twelve-letter display (stimulus offset). Each tone corresponded to one of the three rows of letters and served as a cue indicating which row was to be reported. When a tone closely followed the stimulus offset, subjects were normally able to report the four letters in the designated row with nearly a hundred percent accuracy. All twelve letters, thus, must have been maintained in memory throughout the time interval between stimulus offset and the onset of the tone. As the interval between the stimulus offset and the onset of the tone increased, recall accuracy decreased. When the tone followed the offset by as much as five hundred milliseconds, recall performance deteriorated to a point where individual letters were recalled no better under the partial report procedure than they had been under the whole report procedure. Thus, after about a half second, only about four letters

remained available for recall. Sperling (1960, 1963) suggested that these results reflect the fact that after stimulus offset, the initial sensory memory fades over approximately five hundred milliseconds. The four letters which the subjects were able to report would then represent information which had been entered into a more permenent form of storage prior to their fading from iconic memory. Some form of verbal rehearsal may be involved at this point in the processing sequence.

2. Visual Masking

Research generally suggests that iconic memory maintains information for between one hundred and five hundred milliseconds under normal viewing conditions (Lindsay & Norman, 1972). But time alone is not the sole factor influencing the loss of information from iconic storage. The rate of loss of information is found to change as a function of contrast between the intensities of the stimulus display and the background stimulation. A brightly flashed display which is both preceded and followed by intervals of darkness may be perceived for a number of seconds (Sperling, 1963). In addition, the presentation of patterned stimulation closely following the stimulus offset often appears to "mask" or "erase" the iconic image. The strength of this masking effect seems to increase over the first twenty milliseconds and decrease after one hundred milliseconds (Neisser, 1967). Visual masking probably occurs for readers whenever they focus on new material. Haber (1970) suggested that "it should not be regarded as mere coincidence that the duration of iconic storage and the minimum fixation time in reading are both about a quarter of a second" (Haber, 1970). This duration may be the time needed to perceive and extract information once fixation has occurred. But caution must be taken in attempts to infer the characteristics of "steady-state" or continuous input processes from "transient" input experiments (Sperling, 1963).

## B. Development and Iconic Memory

### 1. Processing Single- and Multiple-Item Arrays

If the study of iconic memory does indeed provide useful knowledge about our ability to process the rapidly changing stimulation which is encountered as our eyes move sacadically across a printed page, then a review of possible developmental changes in the ability to process briefly presented stimuli is certainly in order. Research in this area generally suggests that children as young as five years seem to be essentially as accurate as adults in reporting individually presented stimuli such as simple outlined geometric forms (e.g., Haith, Morrison, & Sheingold, 1970; Haith, Morrison, Sheingold, & Mindes, 1970) or horizontal and vertical bars (Liss & Haith, 1970) across a wide range of very brief tachistoscopic exposures. This finding holds up even when the duration which the stimulus remains in iconic memory is assumed to be limited by the use of a visual "noise" mask following stimulus offset (Liss & Haith, 1970). However, performance for five year-old children is found to be strikingly limited as compared to ten year-olds (Liss & Haith, 1970) and adults (Haith et al., 1970b; Liss & Haith, 1970) when multiple-item arrays are presented. While five year-old children are only able to report an average of 1.6 items when the number of tiems in the array has increased to four, adult recall is nearly perfect to this point.

### 2. Developmental Findings Explored

How can we account for the deficit which young children show in processing briefly presented, multiple-item arrays? Do young children simply possess iconic memories that are far more limited in capacity or far more subject to rapid decay than those possessed by older individuals? One way to answer these questions is to use a partial report technique to explore how much and how long visual information is iconically stored after stimulus offset. Sheingold (1973)

employed a "tear-drop" shaped indicator as a post-stimulus cue which indicated which item in a tachistoscopically presented, eight item array was to be reported. Stimulus offset for children five, eight, and eleven years old and adults was followed after a variable interval by the teardrop indicator. The five year-olds were found to actually perform slightly better than the adults when the indicator followed the offset by as little as fifty milliseconds. As this interval grew in length to one hundred fifty milliseconds, performance dropped for all ages of subjects and appeared quite similar. After one hundred fifty milliseconds, the performance of the youngest subjects continued to deteriorate, while that for the older subjects gradually leveled off at a relatively higher level (four to five items). Apparently, short-term visual memory in young children is similar to that of older individuals for the first one hundred fifty milliseconds; after that duration, the performance of older individuals becomes superior, presumably because the older subjects are more efficient in processing the information held iconically into a more permanent form by the time one hundred fifty milliseconds elapses.

Haith (1971) suggests that there are three general activities involved in processing the types of briefly presented shapes which we have been discussing. First, a complete record of the visual stimuli is maintained briefly by individuals of apparently all ages. Next, individuals of around eight or more years of age then visually encode the stored information when such a code is available; when no such visual code is available, the eight year-olds probably do little encoding, while still older subjects may turn to an abstract code. The third activity, which only the oldest subjects are assumed to engage in, involves the visual rehearsal of the encoded material. If the stimuli used by Haith and his colleagues had been as easily encoded into a verbal form, as had those used by Sperling (1963), it seems likely that rehearsal in these studies would have taken a more verbal form. Whatever form the encoding and rehearsal might

take, development seems to be accompanied by an increasing likelihood that strategies involving encoding and rehearsal will be used. Haith (1971) speculated that verbal rehearsal may play a useful role as a strategy for creating sequential information from simultaneous input.

Prior to their identification, letter strings which form words may have to be processed in a manner similar to that of the arrays studied above. The apparent deficit young children show in processing briefly available multiple element arrays may then play a role in the difficulty young children experience in the acquisition of reading skills. By the time children are ten years old, they are often relatively good readers. Also by this age, they appear to have improved considerably in their ability to process multiple-element displays (e.g., Liss & Haith, 1970). At present, we do not know whether the development of one ability bears any direct relation to that of the other; possibly the development of both abilities can be attributed to an additional factor. Certainly further research in this area is needed to help clarify this issue.

C. Information Scanning in Iconic Memory

There is general agreement that the information maintained in iconic storage is selectively scanned or retrieved, but the rate and manner of scanning this information while it is stored has been much debated (cf. Norman, 1968; Treisman, 1969). Almost seventy years ago, Huey (1908) argued that reading often involves the parallel processing of stimulus material. His argument was supported by the work of Cattell, which suggested that the minimum duration at which a word can be identified is often no greater than the duration found for letter identification. In contrast, Gough (1972) cited evidence using reaction time procedures, suggesting that response latency decreases in various tasks with a decrease in the number of letters in a word. Gough (1972) suggested that iconic memory for written material is scanned in a serial fashion, with information

recovered as individual letters at a rate of between ten and twenty milliseconds per letter. At fifty to one hundred letters per second, this rate is certainly fast enough to be consistent with normal reading rates. These estimations of scanning rate are partly based on the finding that the number of letters that subjects can report, up to their span of apprehension, increases at a rate of one additional letter for every ten to twenty milliseconds increase in duration that a matrix of random letters is maintained in iconic storage (e.g., Sperling, 1963). A patterned mask is presented immediately following the stimulus offset in these studies in an attempt to erase the iconic image, and thus control the duration which information is maintained at this level.

Haber (1970) presented subjects four-letter "words" and reported scanning rates similar to those reported by Sperling (1963). But when Haber had his subjects practice on this task for several days, he found that they acquired the ability to scan the four-letter "words" as rapidly as they could scan for a single letter. This latter finding appears to provide evidence for the possibility of parallel, rather than serial scanning in practiced subjects.

The logic behind Sperling and Haber's studies relies heavily on the assumption that a visual mask stops all ongoing perceptual processing (Brewer, 1972). An alternative approach to the problem of parallel versus serial processing uses reaction time procedures and avoids this assumption. Egeth et al. (1972) explored the relationship between reaction time in two detection tasks and the number of elements in a display presented for one hundred fifty milliseconds. The displays consisted of one to six letters or numbers which appeared equally often in any of twelve different locations. One detection task required same-different judgments; the other required visual search for a predefined element of the display. If individual elements of a display are processed in a serial manner, each additional item in the array would be expected to add to the total

time required to respond. Alternatively, if the stimulus elements are processed simultaneously or in parallel and processing capacity is not exceeded, additional items in the array would not be expected to add to the total time required to respond. The latter alternative was supported, for a flat function was generally found, relating response latency to the number of elements in the display.

While the evidence presented thus far has been inconclusive in answering the question whether letters are extracted from iconic memory in a serial or parallel manner, a brief exploration of possible reasons for the apparent discrepancies may be useful. Recall that in our earlier discussion of letter-string perception, evidence was cited which suggested that the number of items in an array affects perceptual performance mainly when the individual letters composing a string are confusable (e.g., Estes, 1972). Perhaps Haber's (1970) practiced subjects underwent a form of perceptual learning which allowed them to attend to alternative discriminative features or to ignore some redundant features of the array. Both these forms of perceptual learning might be expected to reduce the confusability between letters in his four-letter "words".

## D. Data- and Resource-Limited Processing

### 1. Norman and Bobrow's (1975) Model

A view of information processing that appears relevant to our discussion is presented by Norman and Bobrow (1975), who contend that the performance of a process can vary with the nature of the input data and the amount of processing resources allocated to the process. All systems possess a limited amount of processing resources (e.g., memory, processing effort, communication channels). Different processes may compete for and share portions of these limited resources. The operation of one process will not interfere with that of another, so long as the amount of resources they jointly require does not exceed the total amount available. When the amount of resources available is exceeded by the joint

requirements of processing activities, selective resource allocation takes place, and the performance of at least one of these processes will deteriorate.

We often find that better performance will result from the allocation of more resources to a task. Whenever this proves to be the case and performance on a task can be improved by an increase in the amount of processing resources, the task is considered to be "resource-limited". As additional resources continue to be allocated, many tasks reach a point where such increases have no additional influence on performance. That is, a point is reached on these tasks where all the processing that can be done has been done. All variation in performance on this task from this point on depends solely on the nature of the data received. Whenever this point is reached, the task becomes one that is considered to be "data-limited".

An important aspect of Norman and Bobrow's (1975) model is that performance on most tasks is viewed as being either resource- or data-limited, depending upon whether or not the allocation of additional processing resources can influence performance. Thus the allocation of additional resources for a task that is data-limited does not alter performance, but changing the nature of its data does. Consider the effect which the imposition of conditions that increase demand upon a systems limited resources would have upon a task in which performance is data-limited. Such a condition might result in this task's shifting from one that is data-limited to one that is resource-limited, for now there might be insufficient resources for maximum performance. Furthermore, such a shift would be more likely for data-limited tasks whose top performance require most of the available processing resources. Tasks whose data-limited performance requires less resources would be less likely to undergo such a shift.

2. Discrepant Findings Reconsidered

Norman and Bobrow's (1975) model seems to provide a useful framework for

viewing the apparently discrepant findings which have been used to support both serial and parallel processing views. Many of these discrepant findings may have resulted when tasks were data- limited in one case and resource- limited in another. For example, a good deal of extra processing resources may have been needed to accurately process each additional letter in Sperling's (1963) and Haber's (1970) initial studies. If the total resources required for processing these letters exceeded the total amount available, the involved operations would interfere with one another, causing the entire task to become resource-limited. Presumably this interference is reflected in the fact that the careful processing of each additional letter added to the time required for processing. During their ensuing practice sessions, Haber's subjects may have undergone a form of perceptual learning which resulted in a decrease in the amount of resources needed to process each letter. Assuming this decrease was sufficient to lower the total demands on the resources to a point below their availability, the task would then shift to one that was data-limited. The operations involved would now not interfere with one another and could function simultaneously.

The finding that the number of items in an array does not necessarily affect performance in the detection of a target when the elements are not confusable (e.g., Egeth et al., 1972; Estes, 1972) can likewise be accommodated by Norman and Bobrow's model. Presumably much more processing resource must be expended to process confusable than nonconfusable items in an array, and the processing system is likely to be data-limited when there are nonconfusable targets and resource-limited when there are confusable targets.

3. Attention and Automatic Information Processing

Factors which are found to relate to selective attention (e.g., Broadbent, 1959; Hagen & Kail, 1975; Treisman, 1964, 1969) may be some of the same factors which are involved in the selective allocation of processing resources to

competing processes on resource-limited tasks. For example, information related to the perceived location of an auditory message appears to be used in the selective attending to one message at the expense of another (e. g., Treisman, 1969). Presumably information which is not perceived as emanating from the attended to location would receive a smaller allotment of processing resources than information which receives the most attention. In a similar manner, the general finding that the ability to attend selectively undergoes improvement with development (e.g., Hagen & Kail, 1975) can relatively easily be interpreted as an improvement with age in the ability to allocate processing resources in a particular manner.

While performing a complex task at first often requires a good deal of conscious effort, an interesting change often takes place when the task is repeatedly practiced. Gradually, performance on the task may appear to become increasingly automatic, requiring less and less conscious effort. In terms of Norman and Bobrow's (1975) model, learning appears in this case to have resulted in increased performance with no extra allocation of resources. The acquisition of automated reading skills has long been considered an important aspect of reading competence (e.g., Huey, 1908). Recently, modern experimental procedures (e.g., LaBerge, 1971: LaBerge & Samuels, 1974) have been used to explore more precisely how performance on highly learned tasks differs from that on less well-learned tasks. Findings from these studies have resulted in the construction of theoretical models which attempt to account partially for automated functioning in reading (e.g., LaBerge & Samuels, 1974; West, 1975).

A central finding of research on automatic information processing is that when attention is focused on a stimulus, processing performance often appears no better for highly familiar stimuli than for newly learned stimuli. However, when attention is prevented from focusing upon a stimulus, performance is found to deteriorate far more markedly for a newly learned stimulus than for a highly

familiar stimulus (LaBerge & Samuels, 1974). LaBerge and Samuels (1974) suggested that these results are found because perceptual processing prior to the focusing of attention upon the task can take place only for highly familiar stimuli. Also consistent with such findings is the view that processing of highly learned stimuli often remains data- limited, even when the distraction condition is imposed, while the processing of newly learned stimuli become resource- limited when the same distractions are imposed (Norman & Bobrow, 1975).

4. Development and Processing Limitations

Young children (i.e., approximately eight years and younger) often have shown a marked deficit in their ability to process multiple-item arrays which are available for only brief inspection (e.g., Haith, 1971). Norman and Bobrow's model can be used to account for a portion of this deficit if it is presupposed that processing often becomes resource-limited at an earlier point for young children than for older individuals. Young children may be either more limited in their processing resources, or allocate their resources in a manner which limits the amount available for use by relevant processes. Development is presumably often accompanied by changes in the manner of processing particular types of information, with processes often becoming increasingly efficient or automatic with practice and experience. As Haith (1971) pointed out, young children often seem to lack strategies for encoding simultaneously presented items into sequential forms. While we will consider the whole question of processing strategies in more detail in the following sections of this paper, it should be noted with respect to our current discussion, that young children often seem to fail to allocate resources to certain processes (e.g., rehearsal).

While iconic memory may play an important role in the reading process, there are presently no compelling reasons to suspect that the nature of information iconically stored varies significantly between individuals of differing ages

or reading abilities as long as their visual input is equal. The information entered into iconic storage as eyes move sacadically over a page is likely to vary from individual to individual, though. Studies of eye movements during reading indicate that the fixation patterns of good and poor readers differ considerably (e.g., Buswell, 1920); additionally, evidence suggests that young children may sometimes terminate visual search prematurely as compared to older children (e.g., Vurpillot, 1968). But when the same information is focused upon, this information apparently takes a similar form in the iconic memories of most individuals.

Thus, significant differences between skilled and unskilled readers do not presently appear to have as their locus differences in the actual low-level storage of sensory information. Major processing differences seem more likely to be found in the strategies and skills which readers of differing abilities use in scanning and processing information after it has been temporarily entered into iconic memory. Young children seem to have particular difficulty with processing simultaneously presented arrays (e.g., Haith, 1971), and experience seems to be one important factor in determining how much material is processed (e.g., Haber, 1970). Just what changes take place with experience and development are presently unclear, but further work on selective information processing seems to be one useful course of study. Elaboration of the changes that occur as processing becomes increasingly automated with experience is also likely to prove a fruitful line of research. The processing model presented by Norman and Bobrow (1975) seems to provide one useful framework for organizing the variety of findings coming out of these lines of study. Hopefully, this model will help suggest useful lines of research.

## VI. Precategorical Storage

Earlier in this paper, it was argued that perception takes place over time.

This argument is particularly convincing when one considers language perception, for speech sounds are defined by changes in acoustic energy which take varying periods of time. The nervous system presumably must possess a mechanism by which such serially received signals are stored, making their simultaneous processing possible (Crowder, 1972; Neisser, 1967). The next level of information storage which we will discuss is assumed to play a role in the accumulation of useful sized chunks of relatively unanalyzed and highly transient information which allow the simultaneous analysis of elements.

Storage at this second level can be described as "precategorical", because the information maintained here appears to have not yet received careful categorization. In some respects, precategorical storage is similar to sensory information storage, for both only briefly maintain material that appears to have received little prior processing. Research on the precategorical level of storage has generally centered on information received through auditory channels. Indeed, the argument can be made that precategorical storage is actually an auditory sensory store. But in the present paper, we will argue that the characteristics of precategorical storage are sufficiently distinct from those of sensory storage to justify placement of precategorical storage at a somewhat different level in the processing sequence. Presumably, precategorical storage is above the level of sensory storage and below a level where careful, attentive processing is assumed to take place.

### A. Methodological Problems

Many methodological problems arise when one attempts to study the characteristics of lightly processed information, for there is always the possibility that the information we are attempting to tap either has been forgotten or has received additional processing by the time a response is made. Indeed, the act of merely responding is likely to require some degree of additional processing

which alters the nature of the stored information. Sperling's (1960, 1963) partial report technique appears likely to minimize this problem in the study of iconic storage, for this technique provides a basis for inferring what information must have been available at the time the post-stimulus cue was presented. Two general procudures that provide findings relevant to a discussion of precategorical storage will be discussed. One widely used procedure involves exploring the characteristics of information which has not benefited from attentional inspection; a second procedure involves a study of the characteristics of memory curves as they relate to immediate ordered recall of rapidly presented supraspan lists.

B. Memory for Nonattended Information: Echoic Memory

1. Selective Attention Studies: A Rationale

Selective attention experiments have been used extensively in studies exploring the processing of both attended and nonattended information. A rationale for such experiments was stated clearly by Broadbent (1959), who argued that human information processing capacity is quite limited. When more information is presented than can be processed, a condition of information overload is created, and only a selected portion of the information is able to receive attentive processing. Broadbent suggested that information is first held briefly by a very short-term storage mechanism which, following Neisser (1967), will be referred to as "echoic memory". In Broadbent's scheme, part of the information held in this very short-term store is able to pass through a selective "filtering" mechanism and receive attentive processing. The information remaining in echoic memory, information which has not passed through the selective filtering mechanism, does not receive attentive processing and rapidly fades from memory. While the exact nature and location of the selective mechanism has been much debated (e.g., Deutsch & Deutsch, 1963; Norman, 1968; Treisman, 1964, 1969), there is considerable

evidence of an echoic type store for information that has not received careful attentive processing.

2. Characteristics of Echoic Memory

In one experiment, subjects were given the task of memorizing dichotically presented sequences of digits (Broadbent, 1958). The rate of digit presentation was rapid and subjects, unable to report all the digits, found they could attend to only the digits presented to one ear at a time. While the digits presented to the attended ear were accurately recalled, those digits presented to the other, non-attended ear were only recalled accurately if they had been presented just prior to a shift in attention to this previously non-attended ear. The information presented to the non-attended ear was not recalled accurately after the passage of a brief period of time, presumably reflecting the rapid decay of information from echoic memory.

Glucksberg and Cowen (1970) also used a dichotic listening task to explore memory for non-attended auditory material. Subjects were required to shadow prose presented to one ear; after variable intervals, subjects were asked to recall single digits that had been embedded in prose presented to the non-attended (not shadowed) ear. The accuracy of recalling material presented to the non-attended ear was found to decrease in a negatively accelerating fashion when the time interval between when the material was presented and when attended to increased from zero to five seconds. No memory was found for non-attended information when the attentional switch was delayed for five to twenty seconds. One conclusion that can be drawn from these results is that while the material presented to the non-attended ear is available for a short duration, it is not transformed into a more permanent form without additional attentional inspection.

Differential memory for attended and non-attended material and the effect of order of report were explored in a study where subjects were dichotically

presented four-number lists to each ear at a rate of two pairs of numbers every second (Cryden, 1971). Subjects were instructed to attend carefully to and rehearse those items arriving in one ear. Following each presentation trial, subjects reported the numbers presented to each ear. On some trials the numbers presented to the attended to ear were to be reported first; on other trials the numbers presented to this ear were to be reported second. For both orders of recall, information in the attended ear showed a slightly bowed serial position recall curve; the curve for the non-attended ear was a sharply rising function. The attended information tended to be recalled more accurately than the non-attended information, especially with respect to information about the temporal position of items. The sharply rising function (i.e., recency effect) found for the non-attended ear is consistent with the view that information presented to this ear had been stored in the rather limited capacity echoic or "preperceptual" (Bryden, 1971) auditory store.

Contrary to expectation, recall of information presented to the attended ear, as compared to that presented to the non-attended ear, showed a relatively greater deficit when reported second. Thus, the attended information was apparently more subject to output interference (i.e., the active recalling and reporting) than the non-attended information. Possibly a rentention strategy which only the attended information normally benefitted from was disturbed by the act of recalling the non-attended information. The differing serial position recall curves and the differential effects of order of recall led Bryden to conclude that attended and non-attended information appear to be stored in quite different ways.

The estimation of the length of time which the non-attended information in echoic memory survives appears to be somewhat longer under Bryden's experimental conditions than under those conditions reported earlier. Neisser (1967) reviewed several studies which attempted to estimate the length of time non-attended auditory information endures and found estimations ranging from a few seconds up to approximately ten seconds. The reasons for such discrepant estimations are at

present unclear. Possibly, the "non-attended" channels are in fact receiving a limited and variable amount of attentional resources.

### C. Precategorical Acoustic Storage

The information which one processes while listening or reading is received in the form of rapidly changing, ordered stimulation which is either acoustic or visual in nature. While information received through either modality seems likely to be processed in similar ways at the highest levels, modality-based differences may occur in the processing which takes place at lower levels. Both reading and writing involve the temporary maintenance of the immediate, ordered flow of stimulation, for units must be analyzed whose constituent elements both occur at different points in time and must be simultaneously registered. There are indications that our immediate memory system does not always perform equally well for information acquired through acoustic and visual modalities, and it will be to this "modality effect" that we turn next.

#### 1. The Modality Effect

When subjects are rapidly presented supraspan lists for immediate recall, lists presented auditorily are often recalled somewhat more accurately than lists presented visually. Crowder (1970) explored this modality effect by visually presenting subjects with a series of none individual digits on a screen at a rate of two digits per second. Subjects viewed these stimuli under three different experimental conditions. In one condition, subjects were instructed to vocalize the names of the numbers as they were presented (active vocalization condition). In another condition, subjects were to remain silent while a tape recording was heard to pronounce each digit as it appeared (passive voice condition). In the remaining condition, subjects were instructed to read each digit to themselves as it appeared on the screen (silent condition). Thus, the visual input was accompanied by auditory input in only the first two conditions

(active and passive vocalization). The serial position curve for accuracy of recall indicated that mode of presentation had little differential effect on the accuracy of recalling the early and medially positioned items. Under all three conditions, recall was relatively good for primacy items, and relatively poor medially positioned items. In contrast, a good deal of difference was found between the two modalities in the accuracy of recalling the last three items presented (recency positions). Subjects in the two auditory conditions made few errors, while subjects in the visual condition showed a much less marked recency effect. Crowder (1971) attributed this modality effect to "precategorical acoustic storage" (PAS), which, he argued, has many characteristics in common with echoic memory. Presumably the most recently presented items were recalled more accurately under the auditory input conditions because auditory information receives the benefit of storage in PAS, resulting in an extra source of information beyond that which is available through visual input. The ability to postpone the classification of input is likely to be particularly important for auditory information, for sounds become meaningful only as they are defined by changes which occur across time (Neisser, 1967).

The major source of evidence on the characteristics of PAS is found in a series of "stimulus-suffix" experiments, in which subjects were auditorily presented with a series of digits at a rapid rate of two to four items per second. (Crowder, 1971a, 1971b, 1972). The final digit in these lists was followed by a sound, the stimulus-suffix, which was both expected by the subject and known to be irrelevant to the memory task. The stimulus-suffix was made redundant to avoid increasing the memory load. In some cases, subjects were told that this sound signalled that it was time to start recalling the list. When the stimulus-suffix was a redundant "zero" (Crowder, 1971a) or a vowel-lengthed speech sound (Crowder, 1971b), recall of the last few items of the series deteriorated for

auditory input conditions. The recency effect was thus limited in the auditory input conditions and their corresponding serial position curves took on a shape that was characteristic of the curve created by the silent condition of the experiment viewed above.

Crowder (1972) maintained that the addition of a suffix in the auditory conditions left the subjects without the additional information contained in PAS. The resulting serial position curve, thus, reflected only memory for information that was similar to the type received when input comes only through the visual modality. Presumably, each new item of an auditorily presented list exerts a masking or inhibitory effect on previous items due to PAS's very limited capacity. The redundant suffixes apparently were automatically entered into PAS, interfering with the auditory memory for the most recently acquired numbers.

2. Speech-Like Sounds and PAS

One interesting finding which came out of the stimulus-suffix experiments was that PAS appears to be selective about the information it accepts, for tones, buzzers, and white noise did not have the disruptive effect which speech-like sounds had on the recall of the recency positioned items (Crowder, 1971a, 1971b). Variations in the semantic content of a suffix also were found to have little influence on the resulting interference; for example, the tape recorded suffix "zero" was observed to be no less disruptive when played backwards than forwards. Another set of stimulus-suffix parameters which was explored centered around the perceived location of the suffix and the quality of the voice which spoke the suffix (Crowder, 1972). When a suffix was perceived as coming from a different location or from a different speaker than the list to be recalled, half-way interference was observed.

Taken together, the above results suggest that PAS may be a specialized mechanism which stores relatively unanalyzed speech sounds. The entrance of

information into PAS does not seem to be consciously controlled to the extent that the redundant suffix automatically seems to cause interference. Yet, cues as to spoken location and identity of speaker were apparently used to reduce the suffix effect. Crowder (1972) noted that the apparent requirement that suffixes be "speech-like" suggests that PAS is a specially adapted mechanism used in speech processing. Certainly it seems likely that some mechanism exists for maintaining speech prior to its final anlysis, for speech is necessarily spread out in time. Halle (1972) pointed out that PAS's selective characteristics may also function as a speaker indentification device. Certainly with respect to these latter selective characteristics, PAS seems to have some of the selective characteristics which have been attributed to some attentional mechanisms (e.g., Broadbent, 1959; Norman, 1972; Treisman, 1964, 1969).

3. Echoic Memory and PAS

Many difficulties present themselves when attempts are made to describe carefully the properties of echoic memory and PAS, for both stores are assumed to retain information that has not benefitted from careful attentive processing. The allocation of attentional resources to their preattentively processed material is likely to result in the transformation of this material into a more permanent and carefully processed form. Yet the very activities of demonstrating the existence of the contents of both stores are likely to result in such transformations. Attention must be directed toward the information maintained by these stores before any attempt can be made at recalling their contents.

Estimations of the length of time which information is held in precategorical storage differ considerably. Crowder (1972) has estimated that PAS retains information for only a few seconds, whereas Bryden's (1971) estimation for echoic memory was several seconds. One reason for these differing estimations seems to be that precategorical storage possesses a very limited capacity, with the

differential entrance of new information into storage often resulting in differing degrees of loss for previous contents. For echoic memory, another possible reason for the differing estimations of the rate of loss of information centers around the possibility that even the "non-attended" channels may often receive some portion of attentional resources. This is particularly likely to be the case where subjects know that they must later recall items presented to the "non-attended" ear (e.g., Bryden, 1971). Because little is known about the properties of echoic memory and PAS, we are unable to state clearly just what the relationship is between these two storage mechanisms. Possibly, they are different manifestations of the same storage mechanism; or perhaps, PAS is a specialized speech-adapted component of a more generalized, precategorical storage mechanism.

## D. Development, Precategorical Storage, and Reading

### 1. Verbalization and the Recency Effect

While relatively little is known about whether or not any significant changes in precategorical storage accompany development, a look at the influence which the modality of input has on the shape of the serial position recall curve for individuals of various ages may be informative. The research which was reviewed above on precategorical storage focuses mainly on experiments in which the stimulus input was through the auditory modality. The presence of PAS, for example, was inferred largely on the basis of an enhanced recency effect, which was found for auditory as compared to visual presentations. Some general characteristics of the recency position of the serial position recall curve are discussed in more detail in a following discussion of short-term memory. However, it should be noted here that the less marked recency effect found for information that was not received in the form of auditory input (e.g., Crowder, 1970) is also likely to reflect information that had not benefitted from careful atten-

tive processing. Presently we will concern ourselves chiefly with that portion of the recency effect which seems to be attributable solely to an acoustic mode of imput, for this is the portion which is assumed to reflect the retrieval of information from PAS.

Considerable research suggests that the verbal labelling of items presented for immediate recall in a variety of serial recall tasks often enhances the recency effect, for adults (e.g., Conrad, 1972; Crowder, 1972; Lindsay & Norman, 1972) and for children (e.g., Hagen, Jongeward, & Kail, 1974). At least one cross-cultural study reported this same enhancement of the recency effect for individuals from a culture that was quite different (Yucatan, Mexico) from that of the subjects used in the majority of the studies (Wagner, 1973). Apparently the verbal labelling of items facilitates their immediate retention and increases the recency effect for most people. Knowledge of this fact seems to be reflected in the behavior of older individuals, who often spontaneously employ overt verbalization as a mnemonic for a variety of tasks, such as that of remembering a telephone number for a brief period. In contrast, young children apparently fail to realize the mnemonic potential which verbalization has, and have to be induced to label items in memory tasks (e.g., Hagen et al., 1974).

2. Oral and Visual Language Processing and PAS

While some of the facilitating effect of verbalization may be attributed to sources other than PAS, a mechanism such as PAS seems likely to account for at least a portion of the most recent end of the recency effect. If this is indeed the case, then there is at least some evidence of the existence of a PAS-like mechanism in younger as well as older individuals. Of course if we assume that PAS plays an important role in normal speech processing, it is not at all surprising that young children possess a functioning PAS-like device which aids them in their processing of speech. In fact, it is just this last point which is of particular importance to our discussion of the reading process. Perhaps

PAS is one factor which helps to make the task of comprehending oral (auditory) language easier than visual language for young children, for PAS would facilitate the simultaneous registration of elements of oral but not visual language. Evidence indicates that the comprehension of competent readers is comparable in both silent and oral reading (Conrad, 1972), suggesting that differences in oral and visual language processing become minimized as reading skills are acquired. The lack of a PAS-like device for visual material may become progressively less important as one learns to register simultaneously the constituent elements of larger and larger visual language units; additionally, unlike sound, visual information remains available for prolonged inspection when necessary.

In summary, what is suggested here is that oral language processing may often be mediated for individuals of all ages by a mechanism such as PAS which facilitates the simultaneous registration of sequentially received auditory information. In contrast, visual language processing may not be mediated by a PAS-like device and an alternative mechanism for the simultaneous processing of sequential visual information must be developed. The ability to simultaneously register constituent components of increasingly larger graphic units may constitute one such mechanism.

## III. Short-Term Memory

### A. General Nature of Short-Term Memory

The most extensively studied level of information storage for adults and children has been referred to under a variety of names, e.g., primary, immediate, working, active-verbal, and short-term memory, and is often considered the first memory of which one has conscious awareness (Norman, 1972). Like the information held in sensory and precategorical storages, the information held in short-term memory appears to be processing-involved. That is to say, short-term memory seems to function as a buffer which temporarily retains information while the

information is receiving immediate interpretation. Unlike the information held in the two lower level stores, the information in immediate memory often receives careful attentive processing. Special strategies and control mechanisms seem to be involved in the manipulation, organization, and synthesis of information here. Processing of information contained in short-term memory can take varying lengths of time, and presumably as a result, mechanisms such as rehearsal are available which can maintain information at this level for an indefinite period.

Evidence generally suggests that information must undergo the level of processing characteristic of short-term memory prior to its entrance into a more permanent form of storage. The distinction between information held in short-term memory and a more permanent memory is generally made on an operational basis, although as was suggested earlier in this paper, temporary and more permanent types of storage may reflect characteristics of information at different levels in a single processing continuum. Possibly germane to the question of the functional discreteness of short-term and long-term memory are reports of brain-damaged individuals who, while apparently unable to store new information for future use, have normal recall of both immediate events and information acquired prior to their injury (cf. Atkinson & Shiffrin, 1968; Lindsay & Norman, 1972). While the issue of the decouplability of short-term from long-term memory has not been resolved, a distinction between these two information stores is made largely on the basis of the length of time during which information is available for recall or use. The presence of information at one storage level does not preclude its simultaneous storage at another level.

B. Language Processing and Short-Term Memory

Short-term memory has often been assigned a central role in oral (e.g., Miller, 1962) and written (e.g., Gough, 1972) language processing, and even has

been described as "the working memory for the mechanisms of sentence comprehension" (Gough, 1972, p. 340). In a study which explored this view, subjects were asked to recall both five-word sentences and lists of five unrelated words (Gough, 1972). When the to-be-remembered sentence was presented before the unrelated words, recall of the unrelated words was significantly more accurate than when the sentence was presented after the unrelated words. Recall order had no influence on this effect. One interpretation of this finding is that when the sentence was received first, it was quickly understood, clearing short-term memory for new information. When the word list was received first, short-term memory was already filled or occupied with rehearsal at the time the sentence was received, and the sentence could only be processed at the expense of some of the words from the word list. This finding certainly suggests that the mechanisms involved in temporarily retaining unrelated words share some limited processing resource with the mechanisms involved in sentence comprehension. Another study reported that the storage of sentences which contained differing grammatical features, such as negative and passive transformations, appears to use up differing amounts of the limited capacity of immediate memory (Savin & Perchonock, 1965). Apparently some processing resources involved with immediate memory are involved in sentence processing.

As one listens to or reads a sentence, the linguistic units which comprise this message may sometimes have to be briefly stored as unrelated items in short-term memory prior to sentence comprehension. Although Gough's (1972) results might be interpreted as suggesting that this storage may not always be an easy feat when the relationship between words has yet to be identified, even a young child is readily able to comprehend relatively complex speech (Slobin, 1971). Yet the same child may have considerable difficulty when he attempts to comprehend the written form of this linguistic message. An equal

number of words presumably have to be stored in short-term memory prior to comprehension for both listening and reading. Perhaps the size of the linguistic units that enter the child's short-term memory when he is attempting to read are smaller than those units involved when he is listening. For example, units the size of phrases may often be involved when the child listens, while units only the size of letter clusters may be involved when he attempts to read. If this is the case, then a greater burden would be placed on the child's short-term memory when he attempts to remember a given number of words obtained by reading, as compared to listening.

As reading skills develop, the size of the linguistic units which enter short-term memory may grow, and increasingly large linguistic messages may come to be processed in short-term memory. Partial support for this view is found in studies of eye movements, for competent readers are able to read a message using fewer eye movements than beginning readers (e.g., Buswell, 1920). It has long been recognized that one's eyes are normally focused a little ahead of the place in the text that is being read aloud (Huey, 1908). "Eye-voice span" research offers direct support for the view that a competent reader enters larger chunks of information into immediate memory, because the distance a reader's eyes focus ahead of his voice is found to increase as a function of how fast he is able to read. Additionally, an increase in the length of the eye-voice span is found with development (Levin & Kaplin, 1970). Presumably, text that is not fixated upon while it is spoken is stored in short-term memory.

C. General Characteristics of Short-Term Memory

Perhaps one difficulty an individual has in learning to read centers on the difficulty of briefly storing the words of a sentence while simultaneously attempting to derive their contextual meanings. The origins of this difficulty may lie in places such as the following: the number of items which must be entered

into short-term memory may exceed storage capacity; the duration during which information must be stored may exceed the ability of short-term memory to maintain information; the type of information entered into short-term memory by low-level processing mechanisms may be inappropriate for language comprehension; and the activity of processing written material may have a potentially disruptive influence on short-term memory. A closer look at some characteristics of short-term memory is a necessary first step in the exploration of some of these possible origins of reading problems.

1. Capacity of Short-Term Memory

While most people are reasonably good at repeating short lists of unrelated words, it has long been recognized that there are severe limits to the number of discrete items which can be "kept in mind" at one time. Miller (1956) reviewed a number of studies exploring this capacity and concluded that we are able to maintain only about seven plus or minus two unrelated items in immediate memory at one time. The limited capacity of immediate memory appears to impose a restriction on the amount of information which one is able to process during a given period. Miller suggests that "By organizing the stimulus input simultaneously into several dimensions and successively into a sequence of chunks we manage to break (or at least stretch) this information bottleneck" (Miller, 1956, p. 95). Indeed, lists of unrelated multi-syllable words are no more difficult to memorize than lists of unrelated single syllable words, suggesting that the limiting factor for this memory must be defined in terms of units such as chunks which do not connote a specific amount of information.

While the nature of such chunking has yet to be carefully elaborated, chunking and organization presumably are a normal aspect of the way information is used. The task of memorizing a list of unrelated items is a relatively rare event. One's normal orientation in processing material involves trying to understand and interpret events rather than memorize them. Normally, we remember

the main events of a story without consciously attempting to memorize them, because attentive comprehension of these events is usually sufficient.

Information is presumably made meaningful by searching for the relationships between units of information and making contact between these units and their semantic representations in permanent storage. Such contact must ease the load of short-term memory and must aid in remembering (Bower, 1972). The reason one is able to process a written sentence containing a large number of words may be in part due to linguistic rules which aid in chunking and organization by specifying the relationships between the words, thus allowing several words to be handled as a single semantic unit. Even by the time children reach the first grade, the overwhelming proportion of their oral reading erros (95%) are grammatically consistent with the preceding context (Weber, 1970). This suggests that even young readers have learned to employ linguistic constraints heavily in their decoding of written text.

2. Information Scanning and Short-Term Memory

The search and retrieval of information from short-term memory is assumed to take place at a rapid rate. Sternberg (1966) employed an interesting paradigm which yeilds evidence relevant to questions about the scanning of information in short-term memory. Subjects first learned a target set of from one to six digits. These digits were presented at a rate of 1.2 digits per second and were presumably stored in short-term memory for a brief duration. After a two second delay, a single digit was presented and subjects were to indicate as quickly as possible whether or not this digit was a member of the target set. Of course, the search of short-term memory is not responsible for the total time required to respond, because operations such as perceptual analysis and response execution also use up time. The duration of interest here is the amount of additional time each item in a target set adds to the total response latency. Sternberg found that response time was a linear function of the number items

in the target set, with each additional item adding approximately thirty-five to forty milliseconds. Using these findings, Sternberg postulated the existence of "an internal serial-comparison process whose average rate is between 25 and 30 symbols per second" (Sternberg, 1966, p. 652). Proving that this "internal serial comparison process" involves scanning short-term memory is difficult; however, there are a few experimental procedures which can at least help to rule out some alternative hypotheses (Sternberg, 1969). For example, if it is argued that this process occurs when the stimulus is first registered, manipulations which slow down stimulus registration (e.g., blurring the stimulus) should result in, not only an increased response latency, but also an interaction with the serial comparison process. A resulting change in the function relating response latency to the number of items in the target set should be found. While these kinds of experimental manipulations are found to increase response latency, they generally leave the shape of the linear function unchanged, with each additional item in the target set still adding thirty-five to forty milliseconds to the response time.

An alternative procedure for studying short-term memory scanning is to have subjects search through lists for specific targets. Neisser (1964) had subjects search lists for letters from target sets which contained from one to tem items. Search was terminated as soon as a member of the target set was located; the duration of interest here is the amount of extra time which each additional item in the target set adds to the total time required to scan each list item. Neisser found that search became more rapid with practice; in addition, he found that after two weeks of practice subjects required no more time to search for targets that were members of one-item target sets than ten-item target sets. Thus, in contrast to Sternberg's (1966) finding, the subjects in this experiment appeared able to scan short-term memory for more than one item simultaneously. Indeed, when the target sets contained only one or two items,

Neisser (1964) found this to be the case even for unpracticed subjects.

How can these apparently discrepant findings be reconciled, particularly for the situation where unpracticed subjects searched for targets from one and two item sets? Fortunately, a seemingly minor procedural difference apparently accounts for at least a portion of the discrepant findings. Sternberg had instructed his subjects to make as few errors as possible, while Neisser had emphasized the importance of rapid responding. When subjects engaged in a Neisser type search task are instructed to work as accurately as possible, a linear function such as the one obtained by Sternberg is found (personal communication with Dr. Robert Pachella; also, an informal experiment conducted by author with Dr. Pachella).

The limited processing model proposed by Norman and Bobrow (1975) may help to explain these findings. Whereas these tasks may be resource-limited when instructions emphasize accuracy, they may become data-limited when accuracy is less important, especially when practiced subjects are used. Both practice and freedom to err would be likely to lower the amount of processing resources required for these tasks, thus increasing the likelihood that the tasks would become data-limited.

3. Acoustical Properties of Short-Term Memory

The question of whether information in short-term memory is defined by acoustic parameters has received a good deal of attention. Clark and Chase (1972) presented evidence suggesting that the comparison of information from verbal and pictorial sources sometimes involves encoding both types of information into a common, abstract representation that is neither "verbal" nor "visual" in nature. The fact that our immediate memory span is no different for words of one to four syllables (Craik, 1968) certainly suggests that even for words, short-term memory is not totally defined by acoustic parameters. While these types of evidence suggest that short-term memory should not be viewed solely in

terms of verbal encoding, the bulk of the data compiled to date has supported the view that short-term memory contains information which is largely verbal in nature.

a. Acoustic, Visual, and Semantic Confusions. Perhaps the strongest evidence supporting the notion that information in short-term memory often has a strong verbal component has come from the study of acoustic confusions. Conrad and Hull (1964) studied the recall of lists of letters which were distinguished by the probability of acoustic confusions between the letters within a list. The highly confusable letters were those letters which were more apt to be mistaken for one another when embedded in noisy auditory signals. The major finding of this study was that errors made on this short-term memory task occurred more frequently on the highly confusable lists. This finding has been replicated by a number of studies (e.g., Baddeley, 1966; Conrad, 1971, 1972).

The relationship between acoustic and visual encoding was explored in a series of short-term memory experiments, in which subjects were presented with letters which were either acoustically or visually confusable (Conrad, 1972). The employment of visual codes would be expected to result in shape confusion, while acoustically based codes would result in acoustic confusion. The result of this study was consistent with that of the earlier studies, for the errors which occurred generally reflected the acoustic confusability between letters. Visual confusability did not seem to be an important factor.

Short-term memory appears to be impaired when to-be-recalled items are acoustically similar, suggesting that information held for immediate use is often stored in a manner which has an acoustic nature. The influence of semantic confusions was explored in a study which presented ten-word lists which were either semantically or acoustically similar (Baddeley, 1966). When recall was tested immediately after the presentation of the lists, unlike acoustic similarity,

semantic similarity has little effect. But when recall was delayed for a twenty minute period during which subjects were engaged in a task requiring immediate memory for digits, semantic and not acoustic similarities impaired performance. The task during the twenty minute period appears to have prevented rehearsal; thus only information in a more permanent store was reflected in the performance which followed. Baddeley suggested that short-term memory and long-term memory employ different coding systems, with short-term memory being acoustically based and long-term memory being semantically based.

b. Verbal Memory. Perhaps there are separate short-term memories for information received from different modalities and the "active verbal memory" (Neisser, 1967) which has received so much study is but one of several such stores. The nature of the information is short-term memory also may vary with the level of attentional focus (LaBarge, 1972). Whether or not these latter alternatives prove viable, the question of the modality in which short-term memory normally maintains oral and written language is of interest. Evidence suggests that for processing oral language, certain acoustic properties are retained at the time the verbal input is transferred into short-term memory. The meaning of a sentence may often be understood only when large units of speech are stored by short-term memory. Written language may also come to be encoded in an acoustic form by the time it is stored in short-term memory.

The visual material which is to-be-recalled in most studied short-term memory tasks is verbal in nature (e.g., digits, letters, words). Evidence is generally consistent with the view that subjects encode these types of material in an acoustic form (e.g., Baddeley, 1966; Conrad, 1971, 1972; Murray, 1967; Neisser, 1967; Sperling, 1960, 1963). Encoding certain types of visual information into an acoustically based code (e.g., phonological, sound-based, word-based) may be a useful strategy for a number of reasons. Verbally encoded material

appears to be more rehearsable and enduring than visually encoded material, possibly because of special adaptations that were necessary for language processing and production. Additionally, a relatively automatic recoding of visual information to a common verbal representation may facilitate the comparison and processing of information derived from various sensory sources.

While both reading and listening may involve the entrance of acoustic images into short-term memory, such images are not necessarily entered into short-term memory prior to some level of semantic identification. The acoustic properties of a particular group of letters which form a word can change with their meaning in a sentence. For example, "read" is pronounced differently in the sentences "he read the book" and "he will read the book". In a similar way, "present" is pronounced differently in the sentences "he will present the data" and "he is present". The appropriate representations of "read" and "present" seem to be determined after semantic identification has been achieved. The question whether or not all written language is normally encoded into an acoustic modality cannot be answered at this time. Certainly the fact that deaf individuals do learn to read implies that acoustic encoding is not always a necessary prerequisite for reading. Both introspective evidence and data collected using electromyographic techniques (Edfeldt, 1960; Feldman, 1975: Hardyack & Petrinovich, 1970; Hardyack, Petrinovich, & Ellsworth, 1967; Locke, 1971) suggest that subvocalization often accompanies reading. Possibly encoding material into a verbally based form facilitates its retention by allowing the time necessary to form useful sized chunks of information. Certainly transformation to an acoustically based code would allow written sentence comprehension to proceed in a manner similar to that of oral sentence comprehension.

4. Information Loss

There are two general reasons why it is difficult to estimate accurately

the length of time which information is stored in short-term memory. First, a limited amount of information can be rehearsed and thus continually maintained in immediate memory. For this reason, estimation of the rate of information loss centers on the question how long information is stored in immediate memory when it is not undergoing attentive processing or rehearsal. Secondly, information which is not rehearsed is not necessarily lost from short-term memory at a constant rate under all conditions. For example, interference resulting from attempts at processing new and similar input may have a disruptive effect on information already stored in short-term memory. For these reasons, factors which influence the rate of information loss must be carefully studied.

a. Rehearsal and Information Loss. Various procedures have been used to prevent rehearsal during the interval between the presentation of to-be-remembered material and its later recall. A common procedure is to follow the presentation of a set of stimuli (e.g., digits, letters, words) with an interval that is filled with an intervening task assumed to preclude stimulus rehearsal. For example, subjects may be presented with an intervening task of rapidly counting backwards by three's from a randomly selected, three-digit number (Peterson, 1966). After spending varying lengths of time engaged in such intervening tasks, the subjects in these experiments are asked to recall the initial stimuli. A typical finding is that recall, while excellent immediately after stimulus presentation, rapidly deteriorates as an intervening interval is increased to eighteen seconds (Peterson, 1966).

If the mere passage of time is the sole variable affecting the loss of unrehearsed material from short-term memory (e.g., Broadbent, 1958), then the above paradigm would appear to be adequate for estimating the rate of decay of a short-term memory trace. However, if the loss of information is largely the result of the entrance of new and similar information into short-term memory's

limited capacity store (e.g., Peterson, 1966; Underwood, 1964: Waugh & Norman, 1965), additional parameters, such as the nature of the intervening task, must be explored.

The serial position recall curve generated by various short-term memory experiments has proven a useful source of data for the study of several parameters influencing the loss of information from short-term memory and its transformation into a more permanent form. When subjects in free- and probed-recall tasks are asked to remember a list of items whose length exceeds the span of immediate memory, the probability of recalling the first and last items on the list is normally greater than the probability of recalling the medially positioned items. The recall advantage of the first items on the list is referred to as the "primacy effect", while that for the last items if referred to as the "recency effect". This recency effect must be partially distinguished from the recency effect associated with PAS (Crowder, 1972), for the recency effect associated with PAS appears to involve a very short time interval and seems to reflect only very recently received acoustic information.

One possible explanation for the "U" shaped function of the serial position recall curve is that the recency effect reflects the retrieval of the most recently received and attended to items from short-term memory. In contrast, the primacy effect reflects information which, as a result of rehearsal and additional processing, is retrieved from a more permanent store (e.g., Atkinson & Shiffrin, 1968, 1971: Ellis & Hope, 1968; Murdock, 1962). Support for this explanation is found in the fact that different factors apparently influence recall of items at the two end positions in different ways. Slowing the presentation rate (e.g., from one item per second to one item per two seconds) is found to enhance the primacy effect, but not the recency effect (Ellis & Hope, 1968; Murdock, 1962). A slower presentation rate seems to allow extra time for

rehearsal and additional processing, thus facilitating the encoding of information into a more permanent form. The rehearsal and further processing of individual items can be made more difficult by presenting subjects with lists of increased length. This manipulation lowers the probability of recall of all items except those in the recency positions which are assumed not to be dependent upon careful processing (Murdock, 1962). The interpolation of a difficult computational task between list presentation and recall appears to interfere with the maintenance of list items in short-term memory (e.g., Peterson, 1966). With respect to the serial position curve, the interpolation of a difficult task during the retention interval is found to reduce the likelihood of recalling items in the recency positions far more than items in the primacy positions (Atkinson & Shiffrin, 1971; Ellis & Hope, 1968). This finding is consistent with the view that the recency effect reflects the retrieval of items temporarily available from short-term memory, while the primacy effect reflects the retrieval of items which have been transformed into a more permanent form prior to the onset of the intervening task.

The provision of a brief rehearsal or study period after list presentation seems to enhance the primacy effect and depress the recency effect for children above a certain age (Hagen & Kail, 1973), suggesting that the first items on the list are apt to receive additional processing during a study period. Atkinson and Shiffrin (1971) report that the probability of recalling an item in a short-term memory task increases with the number of prior oral rehearsals. Why such rehearsal facilitates the more permanent storage of information is unclear. Possibly rehearsal maintains information in short-term memory long enough for additional processing to take place and allows attention to be directed toward particular items in a useful manner.

When subjects are given a series of short-term memory tasks, both the

primacy and recency effects are found on each individual trial. However, if recall of all stimulus items is tested for at the conclusion of the entire series of trials, the recall of those items which occurred in the recency positions of their lists is poor. In contrast, those items which occurred in the primacy positions in their lists are recalled far more accurately than other list items (Atkinson & Shiffrin, 1971; Madigan & McCabe, 1971). Subjects in these experiments appeared to have employed strategies which relied upon short-term memory for storing the recency items during the individual trials, while processing the primacy items in a manner which facilitated their transformation into a more permanent form.

b. Interference, Information Loss, and Reading. The question of whether the loss of information from short-term memory is due to the mere passage of time or to the interference from similar information is not answered by the preceding experiment. For those experiments do not adequately distinguish between loss due solely to the passage of time and that loss resulting from interference from the intervening tasks. In an attempt to separate these two factors, J. Reitman (1971) developed a procedure that appears to eliminate rehearsal during the retention interval without the introduction of interfering material. Subjects in her experiment engaged in a difficult tonal signal-detection task during a retention interval of fifteen seconds. While no rehearsal appears to have taken place during the intervening detection task, the recall performance at the end of the retention interval was excellent, indicating that information had not been lost due to the passage of time alone. When the tone of the signal detection task was replaced by a single repeated syllable, one-quarter of the words were forgotten. This latter finding suggests that interference from similar signals is one factor influencing the loss of information from short-term memory.

Atkinson and Shiffrin (1971) employed Reitman's paradigm in an attempt to explore the circumstances under which information is transferred from short-term to more permanent storage. Does transfer occur only at the time information is presented and rehearsed, or does transfer occur throughout the entire period that information is maintained in short-term memory? To answer these questions, subjects engaged in a tonal signal-detection task for either one, eight, or forty seconds following the stimulus presentation (pentagrams). One-half of these retention intervals were immediately followed by an additional retention interval in which the subjects were to engage in a difficult arithmetic task for thirty seconds. Presumably, all information stored only in short-term memory (i.e., information not yet transformed into a more permanent form) would be lost during this second retention interval.

Subjects were able to recall the stimuli accurately on those trials where the retention interval was not followed by the arithmetic task. Thus, Reitman's (1971) finding was replicated because the subjects did not seem to lose information from short-term memory due to the passage of time alone. Information loss was found on those trials where an additional arithmetic task followed the signal-detection task. Information in short-term memory seems to have been lost during the retention interval, and only information stored in a more permanent manner remained. The length of time during which information remained in short-term memory without rehearsal or attentive processing (during a signal-detection interval) seems not to have automatically increased the amount of information processed into a more permanent form, as measured by performance after the arithmetic interval. Therefore, information in short-term memory does not become automatically transformed into a more permanent form with the mere passage of time.

Only a limited number of items whose relationships to one another have

yet to be identified can be maintained at one time in immediate memory. When not rehearsed or attended to, stored items apparently remain available for only a brief duration, particularly when attention is focused on other similar information. Both reading and listening seem to require continual attention to information that is quite similar to and disruptive of information already contained in short-term memory. Language processing, therefore, seems to progress in a manner which would encourage a rapid loss of information from short-term memory. Possibly Gough's (1972) finding with respect to the interference which sentence processing causes in the retention of unrelated words can be explained in this way. Word and phrase identification in normal listening appears to be a relatively automatic occurrence, with little need for careful attending to low-level language components. This results in minimal interference. Competent readers may also process some low-level language units in an automatic manner (Huey, 1908; LaBerge & Samuels, 1974; West, 1975). Indeed, the "Stroop effect" appears to reflect the fact that it is almost impossible to inhibit the automatic identification of the meaning of some common words even for children (Rosinski, Golinkoff, & Kukish, 1975; Schiller, 1966).

Automatic processing of small or low-level units may function to ease the load placed on short-term memory by language processing. In contrast to competent readers, unskilled readers may need to allocate a greater amount of attentional resources to low-level language components for accurate identification. This would place an increased burden on short-term memory, because numerous small items would have to be attentively maintained as unrelated units prior to comprehension. The similarity of these informational units to one another may place an additional load on short-term memory. The automation of low-level processing may be one normal aspect of the development of competent reading skills (LaBerge & Samuels, 1974; West, 1975), for this automation would result in a progressive

reduction in the load placed on short-term memory for any given passage. The translation of written information into acoustic codes may sometimes serve to ease this load on short-term memory. Evidence was presented earlier, suggesting that acoustic codes may be relatively more resistant to decay. Additionally, the possibility exists that the lack of similarity between acoustic and visual codes may result in acoustically encoded material receiving somewhat less interference from ongoing visual processing in reading. Once semantic interpretation has been achieved, neither acoustic nor visual material may result in much interference.

D. Development and Short-Term Memory

We have suggested that one reason reading proves difficult for many beginning readers is that the process of decoding written material may place a great burden on immediate memory, when such decoding requires careful attention to small linguistic units. The young child learning to read may experience additional difficulties in his attempts to read. If the memory tapped in the preceding studies is indeed vital to normal reading, developmental differences in the functioning of this memory process become relevant for our discussion. That large performance differences are found for individuals from different age groups on short-term memory tasks is well established. Possible origins of these developmentally predictable differences will now be explored, in the hope that greater light can be shed on the problems facing a child learning to read.

Atkinson and Shiffrin (1968) made a distinction between the invariant or structural features of memory (e.g., short-term memory) and the control processes (e.g., strategies such as rehearsal) through which individuals accommodate the particulars of specific memory tasks. Developmental differences in the use of control processes appear to be a major source of age-related performance differences on short-term memory tasks, and so the following discussion

of developmental differences in short-term memory will explore how the uses of various control processes vary for individuals of differing ages.

1. Verbal Encoding and Rehearsal

a. Observation of Lip Movements. The spontaneous and active encoding of to-be-remembered material into a verbal code during short-term memory tasks appears to be part of a rehearsal strategy adult subjects often use for increasing their recall performance. In contrast to adult behavior, there is evidence that young children often fail to show signs of active verbal encoding and rehearsal in memory tasks. Flavell, Beach, and Chinsky (1966) presented five, seven, and ten year-old subjects with a circular array composed of seven pictures. On each trial, the experimenter pointed to three pictures which the subject was to recall after a fifteen second interval. The array was not visible during the delay interval. The experimenter, who had been trained to read lip movements, watched for signs of verbal activity during the delay period. Seventeen of the twenty 10-year-old subjects, but only two of the twenty 5-year-old subjects, showed signs of verbal activity during the delay interval. The children who showed signs of verbal activity were generally found to recall pictures more accurately following the retention period. Increased verbal activity was found, therefore, to be more likely with age and associated with superior recall performance.

Locke and Fehr (1970) were also interested in whether or not young children use phonological encoding during memory tasks. Instead of observing lip movements, Locke and Fehr observed differences in electromyographic (EMG) readings of the lip movements of subjects looking at pictures of objects whose names either did or did not contain labial phonemes. Children four and five years old were given a recall task in which they observed slides picturing these objects. Subvocalization as measured by EMG readings occurred during picture presentation, but not during a subsequent rehearsal period which preceded recall. Thus, these children

did not appear to use the strategy of rehearsing in a phonological manner. In contrast, adults have been found to show considerably greater labial-nonlabial EMG discrepancies during rehearsal periods for such stimuli, indicating that these adults may have used subvocal speech to rehearse the stimuli (Locke & Fehr, 1970).

While observable indications of verbal activity are fairly easily interpreted as signs of subvocal speech, the absence of such indications certainly does not prove the absence of verbal encoding; it is always easier to demonstrate the existence than non-existence of such processes (Conrad, 1972). Converging evidence from a variety of paradigms which eliminate alternative hypotheses and help to define these processes are needed if we are to increase our confidence in judgments about the absence of processes which cannot be observed directly (Garner, Hake, & Erikson, 1956).

b. Acoustic Confusions. One form of converging evidence is found in a study by Conrad (1971) on the role of acoustic confusions in the short-term memory of three, five, seven, nine, and eleven year-old children. The to-be-recalled material was comprised of two sets of eight colored picture cards. The names of objects in one set of cards were homophones (e.g., cat, rat, hat) and those in the other were non-homophones (e.g., fish, girl, bus). During a pretest practice period, the lengths of the lists of objects were varied and a length was determined for each subject at which his responses were correct 50% of the time for homophones. Lists of these individualized lengths were then used for the subjects throughout the remainder of the experiment for both lists of objects. The actual lengths of these lists were longer for older than younger subjects. Following the practice period, a number of trials were given alternating a set of homophones with a set of non-homophones. The cards were presented face-up, named by the experimenter, and then turned over, face-down, one by one.

The subjects' task was to match these turned over cards with identical cards.

The proportion of correct responses for the set of homophones remained at the 50% level for all age groups; however, the results were quite different for the older children with respect to the set of non-homophones. Up to the age of five years, there was no difference between the accuracy of recalling items from the two stimulus sets. After this age, the non-homophones became more accurately recalled at a steadily increasing rate. This finding suggests that the older children were saying the names to themselves, and the confusability of the homophonic set apparently increased the difficulty of this task for these subjects. The absence of such a homophone- non-homophone effect for the younger children suggests that they had not experienced additional trouble with the like-sounding words, because they were not using an acoustically based strategy for retaining the items. While the above explanation seems probable at least one alternative explanation is available. For it is possible that some words which are perceived as homophonic by adults are not always so perceived by children. Savin (1972), for example, has suggested that young children may often not perceive the rhyming nature of words for which this relationship seems obvious to adults and older children.

c. Induced Verbal Rehearsal. The question of why many young children apparently fail to rehearse material verbally in immediate memory tasks is of great interest. Do the children fail to verbally rehearse material because to do so has no consequence for their following recall performance (e.g., Reese, 1963) ? Or, are they simply unaware of the effectiveness of this strategy as a means for increasing their recall in these tasks? Keeney, Cannizo, and Flavell (1967) conducted an experiment which is relevant to these questions. The subjects in this experiment were selected from the first grade. Using an

experimental procedure generally gollowing that of Flavell et al. (1966), the children were divided into two groups, composed either of those who were or were not spontaneous rehearsers of to-be-remembered material. The children who were observed to spontaneously rehearse during the retention interval were generally found to have superior recall to their nonrehearsing peers. The children in the non-rehearsal group were then instructed to "whisper audibly" the names of the objects in the pictures during the retention period. The result of this induced verbal rehearsal was that these children now performed as well as children in the group which had spontaneously rehearsed the material. Keeney et al. (1967) interpreted these results as supporting "the production deficiency hypothesis", or the hypothesis that the non-rehearsers had initially simply failed to generate useful mnemonic mediators. It is interesting to note that a follow-up session several weeks later revealed that the non-producers once more failed to spontaneously employ verbal rehearsal.

2. Development and the Serial Position Recall Curve

Inspection of serial position recall curves has yielded interesting developmental findings. While the recency effect is usually found across all age groups, the primacy effect is generally found to increase as a function of age, often being absent or depressed for young children (e.g., Atkinson, Hansen, & Bernback, 1964; Hagen & Kail, 1973; Hagen & Kingsley, 1968). Earlier in this paper, evidence was presented suggesting that the recency effect reflects recall of short-lived information from a functionally defined short-term memory, while the primacy effect reflects recall of more permanent and highly processed information. Apparently, young children often fail to engage in the types of processing and encoding activities which facilitate the transformation of the information presented during short-term memory tasks into a more permanent form.

a. Induced Verbal Labelling and Rehearsal. One way to explore the role played by various control processes and mnemonic behaviors is to induce subjects of different ages to engage in activities which are believed to differentially affect both recall and the shape of the serial position curve. Keeney et al. (1967) were able to induce verbal rehearsal in their young subjects who had failed to spontaneously rehearse, with the result that recall performance was effectively increased. Evidence was presented earlier, suggesting that factors which increase rehearsal are also likely to facilitate the transformation of information into the more permanent form, reflected by the primacy effect (Atkinson & Shiffrin, 1968, 1971; Ellis & Hope, 1968; Murdock, 1962). How does induced rehearsal influence the shape of the learning curve for individuals of different ages?

Hagen and Kingsley (1968) looked at the role which verbal labelling played for four, six, seven, eight, and ten year-old children in a serial position recall task. The stimuli used in this experiment consisted of eight cards with drawings depicting familiar animals. A given trial involved briefly showing the subjects each card, turning the card face down, and then proceding to the next card until all cards had been presented and were face down in a row. Subjects were next shown a cue card, and asked to identify the matching face down card. Half the subjects were instructed to label aloud each card with the name of the animal depicted on it as the cards were presented. The remaining subjects were not required to label the cards.

Although recall was found to improve with age, only children in the middle age groups appeared to have benefitted over-all from the labelling condition. Inspection of the serial position recall curve indicated that labelling had facilitated recall of those items in the recency positions, while retarding the recall of items in the primacy positions. Hagen and Kingsley (1968) suggested

that the labelling condition had interfered with the spontaneous, covert rehearsal of the older children. Apparently, simply labelling items enhances their salience for a brief duration, but, at least for unstructured strings of words, does not aid much in the processing necessary for transformation into a more permanent state. Although the extent to which a PAS-like mechanism may account for the enhanced recency effect is unclear, it seems that such a mechanism may account for at least a portion of the enhanced recency effect. Induced labelling may interfere with the use of relevant strategies which transform material into a more permanent form for those subjects who use spontaneous strategies.

What influence does inducing verbal rehearsal have on the shape of the serial position recall curve? A study by Kingsley and Hagen (1969) investigates this question with nursery school children. Some of the children in this study were required to rehearse as well as label to-be-remembered items. Induced rehearsal was found to facilitate recall of items for both the primacy and recency positions. Prompted verbal rehearsal has also been found to increase recall for children of five and seven years of age (Hagen, Hargrave, & Ross, 1973). The effect of inducing overt verbal rehearsal on the recall performance of older children (nine to fourteen years) and adults (college students) was explored by Hagen, Meacham, and Mesibov (1970). Inducing rehearsal in older subjects often appears to increase recall for recency items and retard recall for primacy items. While the older children's total recall was about the same with and without the induced rehearsal, the college students' losses at the primacy end under the rehearsal condition actually resulted in a lower over-all recall score. Therefore, although it appears that induced rehearsal may enhance both temporary and permanent information storage for children too young to normally possess effective, spontaneous rehearsal strategies, such induced rehearsal may

at times interfere with effective spontaneous rehearsal in older children and adults. Similar findings with respect to the effect of induced verbal labelling have been reported in a cross-cultural study in Yucatan, Mexico (Wagner, 1973).

b. Opportunities for Spontaneous Rehearsal. The general pattern of the above studies seems clear. Young children exhibit a recency effect in short-term serial recall tasks, but often fail to exhibit the marked primacy effect so often found for older subjects. The absence of the primacy effect for young children appears to be due to their failure to spontaneously employ active strategies, such as those used by older individuals to facilitate the encoding of information into a more permanent form. When young children are induced to rehearse material, their performance seems to become more like that of older subjects. For reasons that are unclear at present, such induced strategies are abandoned after a relatively brief period by those children who failed to employ them spontaneously in the first place (e.g., Hagen et al., 1974; Keeney et al., 1967). The effect of induced rehearsal is less clear for older subjects. Under some circumstances, induced rehearsal seems to increase the primacy effect (Atkinson & Shiffrin, 1971), but more often it seems to retard this effect (e.g., Hagen et al., 1970). One plausible explanation for this latter retarded performance is that induced verbal rehearsal may prevent older subjects from employing efficient covert rehearsal strategies. A few predictions seem to follow naturally from the preceding argument. Conditions which increase opportunities for use of spontaneous rehearsal should increase the primacy effect for older children, but not for younger children. When conditions are such that spontaneous rehearsal is inhibited or prevented, the performance of older subjects with respect to the primacy effect should decrease and approximate that of younger subjects, who typically fail to employ such

strategies in the first place. Additionally, activities which draw attention away from the most recent items in the recall task for several seconds should retard the recency effect for both young and old subjects.

Findings relevant to these predictions were obtained in a serial position recall task, which contained a condition that increased opportunities for spontaneous rehearsal and another condition that inhibited such rehearsal (Hagen & Kail, 1973). In the facilitation condition, seven and eleven year-old children were instructed to "think about the pictures" during a fifteen second retention interval between stimulus presentation and recall. Children in the distraction condition were instructed to count aloud during the retention interval. In addition to the two experimental conditions, a no-delay control condition was run. Recall of primacy position items remained at a similar low level across all three conditions for the younger subjects. As compared to the control condition, the primacy effect for older subjects was found to increase in the facilitation condition and decrease in the distraction condition. The decrease in the recall of primacy position items for the older subjects under the distraction condition resulted in a serial position recall curve which closely approximated that curve found for the younger subjects in this condition. The recency effect was depressed for both groups of subjects under the experimental conditions. Our predictions concerning the influences of conditions that either encourage or discourage opportunities to rehearse material in a serial position recall task were supported by Hagen and Kail's (1973) findings, and have received support from additional studies (e.g., Sabo & Hagen, 1973).

A variety of mnemonic strategies have been found to differentiate younger from older subjects. Belmont and Butterfield (1971) used serial recall tasks in a number of studies on the development of different mnemonic processes. Subjects were individually presented letters which together comprised to-be-

remembered lists of different lengths. The letters appeared individually in different physical locations for one-half second each. Subjects controlled the inter-letter intervals. Increasing age was found to be accompanied by an increased use of spontaneous rehearsal. Older subjects took more time between letters as the lists grew longer, apparently allowing themselves more time to rehearse the increasing number of items. An increase in age was found to be associated with an increased use of selective tactical non-rehearsal, a careful combination of rehearsal and the use of immediate memory for the most recent items. Thus, older subjects were found to be more likely to tailor various rehearsal strategies to fit the unique aspects of a particular task. The general implications of these findings are consistent with those of the experiments described above. Increased age seems to be accompanied by an increased likelihood that spontaneous, specialized, and active strategies will be used during memory tasks.

3. Differentiation of Memory and Perception

Why is it that unlike older children and adults, young children often fail to take an active and deliberate role in memorizing material? Certainly they are capable of remembering a vast amount of information about events which occur in their daily lives. And young children can easily be induced to employ temporarily mnemonic strategies which increase their recall performance. Appel, Cooper, McCarrell, Sims-Knight, Yussen, and Flavell (1972) proposed that one reason for this failure to take a spontaneous role in memory tasks may be that memorization and perceiving are functionally undifferentiated for young children. Deliberate attempts to memorize information may only gradually emerge as children learn to distinguish memorization from perception. Thus, memory for young children may be largely incidental, a by-product of simply perceiving and interpreting stimuli. To explore this proposal, Appel et al. (1972) presented pre-school, first-grade, and fifth-grade children with stimuli under

two different conditions. The children were instructed to either memorize the stimuli or merely look at them. While the younger children responded to both conditions in a similar manner, older children differentiated between conditions by rehearsing and categorizing the material in the memorization condition. Thus, the "differentiation hypothesis" was supported in this study.

Masur, McIntyre, and Flavell (1973) studied developmental changes in the way study time was divided between items in a multi-trial recall task. The retention interval consisted of a forty-five second study period, during which the subjects had access to any half of the total set of to-be-recalled items. Third-grade and college subjects were found to be more likely than first-grade subjects to select the items for study which they had not recalled in the preceding recall trial. Thus, a strategy of deliberately studying the non-remembered items was used by the third-grade and college subjects only. The younger subjects simply treated all stimuli as if they were the same.

4. Short-Term Memory Development and Reading

Performance on a variety of short-term memory tasks has been found to increase with age. While the reasons for this developmental change in performance are undoubtedly complex, the literature in this area shows considerable consistency with respect to an age-related increase in the probability that certain control processes will be used. When individuals of about ten years or more of age are presented with material which they are expected to later recall, they spontaneously engage in activities, such as rehearsal, which are likely to enhance memory. As individuals become older, the particular mnemonic strategies used increasingly become specially tailored to the unique aspects of the particular recall task. In contrast, young children seem to engage in little mnemonic behavior, making few allowances for the peculiarities of

memory tasks. When young children are induced to employ rehearsal strategies, their performance is found to increase, but normally only so long as they are prompted in appropriate mnemonic behaviors. The reason for this failure to tailor processing strategies to the unique requirements of memory tasks seems to be that these children do not perceive memorization as requiring behavior different from that of simply looking. Young children, therefore, seem to see no reason for allocating their processing resources in different ways for different tasks. The memorization which does take place for young children apparently automatically results as a natural consequence of their perceiving and interpreting the to-be-remembered material.

The allocation of processing resources can be described as growing increasingly flexible and efficient with development, particularly with respect to short-term memory tasks. Immediate memory seems to play an important role in both oral and written language processing. While little is known about the specific mnemonic strategies which may be used in reading, increasing age seems to be accompanied by increased flexibility, specificity, and efficiency in the employment of strategies which ease the load placed on short-term memory by reading. The absence of such strategies in many young children may result in an aggravation of the laready heavy short-term memory load which is assumed to accompany inefficient reading skills.

## VIII. Summary and Conclusions

Discussions on how written English words are recognized have a long history in psychology. Models which propose that words are normally identified by serially mapping individual letters onto speech sounds do not adequately note the difficulties inherent in this task, particularly in light of the highly abstract nature of linguistic units as small as isolated phonemes. One alternative to letter-byletter recognition models if F. Smith's (1971)

feature-analytic model which suggests that whole words are recognized directly from featural information without mediating letter identification. Since words contain considerably more information than is needed for their identification, much of the redundant information in words need not be processed. The processing demands made upon limited resources by reading can therefore be reduced. The superior perceptual performance of words as compared to nonwords supports the feature-analytic theory. The manner in which the use of redundant information changes with development of reading skills is a fertile area of research.

While the feature-analytic model can account for many of the phenomena associated with word identification, this model places a tremendous burden on memory. Separate feature lists would have to be stored in long-term memory for each word. To minimize such memory loads, readers may use their knowledge of the spoken language in decoding text. Written English can be viewed as a visual model of the spoken language. One task for the beginning reader is to discover the invariant relationships which exist between this visual model and the spoken language. The suggestion that readers make use of their knowledge of speech in reading does not mean that they necessarily identify written words by their sounds. The superior perceptual performance found for non-word letter strings which conform to English spelling patterns as opposed to those which do not suggests that readers are able to use orthographic regularities to facilitate word identification. The relationship between English orthography and the spoken language has invariances at more than one level; we should not limit the study of recognition units in reading to units of a single size. Competent readers more frequently use larger units than beginning readers.

Reading necessarily involves the retention of information over time. Units of information which differ in size must be gathered, operations which require varying lengths of time must be executed, and often, the content of a message must be retained for possible future processing. Iconic memory, precategorical acoustic storage (PAS), and short-term memory are mechanisms for retaining information which is to be processed.

Iconic memory is a visual sensory storage mechanism, providing a detailed and accurate record of the visual input for feature extraction and pattern recognition to act upon. Although the content of iconic memory does not appear to differ dramatically for individuals of different ages and skill levels, the manner in which information is extracted, once it is contained in iconic memory, seems to vary greatly. Speed of scanning iconic memory is found to increase with practice (e.g., Haber, 1970). Young children are often found to show a marked deficit in their ability to process multiple-item arrays which they are presented for only a brief duration (e.g., Haith, 1971). As reading also involves the rapid extraction of information from multiple-item arrays, this deficit may account for a portion of the difficulty young children have in learning to read. Research is needed to clarify how the extraction of information from multiple-item arrays becomes more efficient with experience and maturity.

Norman and Bobrow (1975) have proposed a processing model which provides a useful framework for organizing a variety of findings from research on cognitive processes, including short-term visual memory. This model assumes that performance on a task can be limited either by the availability of processing resources or by the quality of the input data. Interference between processes which compete for limited processing resources can occur only on tasks

whose processes are resource-limited. Performance differences obtained for tasks which seem similar may result when one task is resource-limited and another is data-limited. The Norman and Bobrow model may be relevant to development. Perhaps, the younger the individual, the lower the level of complexity at which a task becomes resource-limited. Tasks which are data-limited for older and more experienced individuals -- such as the processing of briefly presented multiple-item arrays -- are more likely to be resource-limited for younger and less experienced individuals. The improved processing performance associated with increased age and practice seems likely to reflect increased efficiency in processing and allocation of resources rather than an increase in the total amount of processing resources. Norman and Bobrow's model also provides a useful perspective for organizing a variety of other reading-related phenomena, such as the increased performance associated with perceptual learning, the automation of various processing skills with practice, and the increasing effectiveness of strategies associated with development.

Although some children experience a great deal of difficulty in learning to process visual language, almost all children acquire their spoken language with relative ease. While the reasons for the difference in ease with which the two language forms are often learned are undoubtedly complex, the modality effect, explored in our discussion of information storage at the precategorical level, suggests one difference between auditory and visual language processing. Spoken language processing appears to be often mediated by a very short-term auditory storage mechanism, PAS, which facilitates the simultaneous registration of small, sequentially received speech segments (e.g., Crowder, 1972). Evidence suggests that the storage of information in PAS occurs with minimal use of limited attentional resources and control exercised in the selection of the particular speech-like sounds to be stored. Prior to an individual's

learning of higher order speech-orthography invariances, the processing of brief visual language stimuli may require a greater amount of processing resources.

Short-term memory tasks and sentence processing employ some of the same limited processing resources. For example, processing a sentence interferes with the retention of unrelated words in short-term memory (Gough, 1972). Sentence comprehension is not possible until all the component parts of the sentence are stored and available for simultaneous interpretation. Therefore, some of the same (or similar) mechanisms responsible for the retention of material in short-term memory tasks seem to play a role in storing uninterpreted component units (e.g., isolated words) while their relationships to one another are being determined. An understanding of performance on short-term memory tasks should lead to a greater understanding of sentence processing. Children, who are inefficient in the allocation of their limited short-term memory and processing resources, may thus be hindered in their visual sentence processing.

In general, performance is found to decrease as the number of unorganized items, or discrete chunks, of information in a task increases. In reading a sentence, therefore, the capacity of short-term memory may be exceeded if a large number of uninterpreted chunks of this sentence must be stored prior to sentence comprehension. Information is more likely to be lost from immediate memory when attention is shifted to new and similar material, possibly because attending to new items reduces the availability of those processing resources needed to maintain information in short-term memory. Low-level linguistic units such as acoustic features are generally more similar to each other and more confusable than higher-level, meaningful units. Beginning readers must attend closely to low-level linguistic units and are therefore likely to experience a more rapid rate of information loss from short-term

memory than experienced readers who are also able to attend to higher-level meaningful units. Practice and perceptual learning increase the efficiency of the decoding task, thereby reducing the amount of processing resources which must be allocated to the task of decoding low-level orthographic units. As reading skills improve, larger and larger orthographic units may become the focus of attention. This would result in an easing of the load on short-term memory, for fewer, larger component chunks of information would have to be stored temporarily. Additionally, attention would be freed to focus on the content of the message, rather than upon the details of the code.

Development is associated with an increased probability that mental activities which limit the loss of information from short-term memory will be employed (e.g., Hagen, Jongeward, & Kail, 1975). Whereas young children do little to facilitate the retention of to-be-remembered material on short-term memory tasks, older children and adults spontaneously use a variety of mnemonic strategies which enhance short-term memory performance. By the age of ten years, for example, subjects often spontaneously verbally encode and rehearse to-be-remembered material and organize it in ways that enhance recall performance. Electromyographic evidence of subvocal speech in readers suggests that verbal encoding is common for both good and poor readers (e.g., Edfeldt, 1960; Feldman, 1975). Perhaps one reason readers translate portions of written text into a verbal code is to enhance their short-term memory for this material. Certainly, it appears that short-term memory "thrives on speech-like input" (Conrad, 1972, p. 237). Older individuals often tailor their mnemonic strategies to the particular requirements of memory tasks (e.g., Belmont & Butterfield, 1971). Competent readers approach the task of reading in a similar way, by actively organizing the material and by sub-vocalizing, even rehearsing, it on selective occasions to boost short-term

memory. In contrast, young children and beginning readers often fail to approach reading in an active and flexible manner, with the result that they have often forgotten the first words of a sentence before they have been able to interpret the sentence. While regressive eye movements are found for readers of all competence levels, these movements occur far more frequently for young and beginning readers (e.g., Buswell, 1920; Smith, 1971). Perhaps novice readers forget the early words of a sentence and must make regressive eye movements to re-present these stimuli to themselves.

Reading is a composite of many subskills and therefore requires the coordination of numerous component processes. The particular repertoire of pattern recognition and memorial processes which make up reading varies according to the age, proficiency, and purposes of the reader. Our understanding of the development and operation of pattern recognition and memorial processes has been enhanced in recent years by research which has adopted information-processing conceptions of mental activities. The essence of the information-processing conception of mental activity is the specification of sets of algorithms which model specific behaviors. One purpose of this lengthy review has been to enumerate the mental processes for which algorithms might be sought to model reading. Since the nature and coordination of the elemental processes which comprise reading change with the age of the reader, an adequate model of reading must describe how the interface among pattern recognition, memory, and reading change with development and skill acquisition.

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